Santa Clara Valley
Groundwater Model Project

Basinwide Groundwater Flow Model

Draft Technical Memorandum

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Prepared for
City of San Jose
and
Santa Clara Valley Water District

by
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Errata

Page 4-12, insert after explanation of rainfall equation

The location factors for the seven rainfall zones in the model are:

- Zone 1: $F_{sj}=1.0$, $F_{lg}=0.0$
- Zone 2: $F_{sj}=1.0$, $F_{lg}=0.0$
- Zone 3: $F_{sj}=0.667$, $F_{lg}=0.333$
- Zone 4: $F_{sj}=0.333$, $F_{lg}=0.667$
- Zone 5: $F_{sj}=0.0$, $F_{lg}=1.0$
- Zone 6: $F_{sj}=0.0$, $F_{lg}=1.0$
- Zone 7: $F_{sj}=0.0$, $F_{lg}=1.0$

Page 4-13, last paragraph, second sentence.

The SCVWD measures recharge in the recharge facilities daily. The daily recordings for the modeled period, however, were not available, so results from the BNDFLO program were used to estimate facility recharge.

Page 4-14, insert after first paragraph.

From the data on table 4-3, Stevens Creek was assigned a catchment area of 21.0 square miles. Stevens Creek was compared to: Permanente Creek, 7.8 square miles (37% of Stevens Creek); Hale Creek, 2.7 square miles (13% of Stevens Creek); and Adobe Creek, 7.3 square miles (35% of Stevens Creek). Penetencia Creek was assigned a catchment area of 21.8 square miles. Penetencia Creek was compared to: Beryessa Creek, 4.5 square miles (21% of Penetencia Creek); and Arroyo de las Coches, 3.4 square miles (16% of Penetencia Creek).

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Section 1
Executive Summary

This report documents a numerical model of groundwater flow in the groundwater basin of northern Santa Clara Valley. The numerical model is based on the hydrogeologic conceptual model presented in the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a). The numerical model provides the Santa Clara Valley Water District (SCVWD) and the City of San Jose with a tool for: estimating the short- and long-term yield of the groundwater basin; evaluating the amount of groundwater that can be safely pumped from the basin; and evaluating the feasibility of recharging reclaimed water into the basin.

Numerical Model Selection and Construction

Model Selection and Study Area

The numerical model used was the U.S. Geological Survey (USGS) groundwater flow model, MODFLOW (McDonald and Harbaugh, 1988). MODFLOW is used to simulate groundwater flow in the Santa Clara Valley Basin, from Coyote Narrows in the south, to the Santa Clara-Alameda County and Santa Clara-San Mateo County lines in the north. The modeled area encompasses most of the alluvial fill in the northern Santa Clara Valley, as defined by the SCVWD.

Data

To assist in the creation of the model, the SCVWD provided well location and completion information, interpreted lithologic information from previously-constructed cross sections, water level measurements, pumping data, and facility recharge data for the model. Water level measurements and pumping data were based on field measurements. Facility recharge estimates were based on the output of a SCVWD program, BNDFLO. Data provided by the SCVWD were supplemented with data provided by the local water retailers, USGS, California Department of Water Resources (CDWR), and consultant studies of local groundwater contamination sites.

Limitations of the data included: relatively few aquifer tests (for estimating aquifer parameters); almost no depth-specific water levels; and an unverified water budget estimate. To partially compensate for these limitations, aquifer parameter values were estimated from previous models and specific capacity data; and wherever possible, water level measurements from production wells were assigned to specific depths (and subsequently, model layers) based on available well completion information and comparing similar hydrographs from known depths.

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Construction

The numerical model comprises six layers, each layer containing 57 rows and 92 columns. Active grid nodes encompass an area of approximately 315 square miles. The smallest cells are 1,000 feet on a side, and the largest cells are 6,000 feet on a side. The model grid is sub-parallel to the longitudinal axis of the Santa Clara Valley Basin, reflecting the predominant groundwater flow direction.

To represent the multiple piezometric heads and hydrostratigraphic complexity of the Santa Clara Valley Basin, multiple model layers were used. Because of the hydrostratigraphic complexity, model layers were based on production well perforation interval incidences rather than stratigraphic continuity. Depths in which few production wells were perforated were assumed to be relatively low-conductivity zones. Model layer bottoms were assigned to the low-conductivity zones.

Horizontal flow boundaries included constant head or no-flow boundaries. Constant head cells were assigned to model cells that simulate San Francisco Bay and Coyote Narrows. All other horizontal model boundaries were represented by no-flow cells.

Horizontal hydraulic conductivities for Model Layers 1 and 2 were estimated from aquifer tests performed at local groundwater contamination sites and from previous modeling efforts. For Model Layers 3 through 6, specific capacity data provided initial estimates for horizontal transmissivities (and subsequently, horizontal hydraulic conductivities). Lithologic zonation based on the conceptual model (CH2M HILL, 1992a) and existing cross sections formed the basis for distributing the specific capacity estimates throughout the basin. Vertical hydraulic conductivities were estimated as a percentage of horizontal hydraulic conductivity. Storage coefficient estimates from aquifer tests and previous modeling studies were used, where available.

The estimated water budget for the groundwater basin included estimates of discharge and recharge components. Discharge components included pumping, subsurface outflow beneath San Francisco Bay, sewer infiltration, and evapotranspiration. Basin recharge components included recharge through gaged SCVWD facilities, infiltration of excess rainfall, underflow from adjacent basins, subsurface inflow through bedrock boundaries, ungaged stream recharge, deep percolation of delivered municipal and industrial water, deep percolation of agricultural water, distribution pipeline losses, and sewer losses.

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Numerical Model Calibration and Verification

Calibration

The model was calibrated to quasi-steady state and transient hydrologic conditions. Because sufficient data for steady state conditions were unavailable, the average groundwater conditions between 1978 and 1982 were used to approximate a steady state period. Transient calibration was conducted for the years between 1970 and 1983.

Calibration success was measured using groundwater levels, groundwater gradients, and flows across model boundaries. Groundwater levels were used most extensively during calibration because these data are actual point measurements made in the field and do not reflect any interpretation.

Hydrographs from wells throughout the basin were simulated successfully using the numerical model; the measured annual water level trends and seasonal fluctuations are produced by the simulated hydrographs. Composite and layer-by-layer piezometric surface maps reproduce features recognized in the basin by the SCVWD.

Verification

Verification of the calibrated model comprised simulating groundwater conditions from 1984 through 1989. Groundwater conditions not used for calibration were successfully simulated using the numerical model. The success of this verification began to establish the predictive ability of the numerical model.

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Uncertainties and Recommendations

Based on the calibration and verification results, the model is useful for evaluating short- and long-term groundwater management strategies. Future improvements to the model should include continuing calibration, including: automatically estimating parameters (including sensitivity analyses); conducting and including results of additional aquifer tests; defining a monitoring well network to gather additional, depth-specific groundwater data; and improving estimates of components in the basinwide water budget.

Section 2
Introduction and Background

The groundwater basin of northern Santa Clara Valley is an integral component of the regional water supply, storage, and distribution systems. The basin's native yield is augmented by artificial recharge of regulated local runoff and imported water. The basin has an estimated operable storage capacity of up to several times its managed, annual yield. The basin also distributes water between artificial recharge facilities and major wellfields.

The managed operation of the groundwater basin is potentially constrained by periods of deficient, as well as surplus, recharge, and storage. During drought periods, when water levels are low, groundwater extractions may be limited by the potential for resumed land subsidence. During wet periods, when water levels are high, the ability of the basin to accept recharge may be limited.

2.1 Project Background

In 1989, the State Water Resources Control Board (SWRCB) directed the Santa Clara Valley Water District (SCVWD) to actively encourage the maximum use of existing water supplies, including reclaimed water, before seeking additional water imports. In October 1990, the SWRCB ordered the San Francisco Regional Water Quality Control Board (RWQCB) to place an average, dry-weather flow limit of 120 million gallons per day on discharges to south San Francisco Bay from the San Jose/Santa Clara Water Pollution Control Plant (SJ/SC WPCP). The City of San Jose subsequently developed an "Action Plan" in response to the pending flow limit. The Action Plan, intended to fulfill the intent of the SWRCB order, includes provisions for both nonpotable and potable reclamation. The RWQCB accepted the Action Plan on October 16, 1991, as a viable alternative to the flow limit.

As a result of these SWRCB actions, the City of San Jose and SCVWD entered into an agreement to cooperate in identifying and developing water reclamation projects and to jointly support and finance the following three projects:

- Nonpotable Reclamation
- Potable Reclamation
- Groundwater Model

This memorandum presents the methodology and results for one task of the Groundwater Model Project.

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2.2 Purpose and Objectives

The purpose of the Groundwater Model Project was to begin building a data base and a numerical flow model that the SCVWD and the City of San Jose can use as tools to help manage groundwater in the Santa Clara Valley Basin. With these tools, the SCVWD and the City of San Jose intend to:

- Estimate both the short-term (e.g., short-term drought conditions) and long-term managed yield of the basin as limited by the potential for pumping-induced land subsidence
- Evaluate the amount of groundwater that water retailers can safely pump at various locations throughout the basin
- Evaluate the feasibility of recharging reclaimed water into the basin

2.3 Scope and Approach

The Groundwater Model Project comprised the following tasks:

- Hydrogeologic Interpretation
- Subsidence Threshold
- Groundwater Flow Model
- Local Models
- Data Management (GIS)

This memorandum presents the construction, calibration, and verification of the numerical groundwater flow model of the Santa Clara Valley Basin. The numerical model is based on the hydrogeologic interpretation presented in the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a). The numerical flow model provides the SCVWD and the City of San Jose with a tool for managing the groundwater resource.

A Groundwater Technical Advisory Committee (GWTAC) was formed to critically review the construction, calibration, and verification of the groundwater model. Members of this committee were internationally recognized experts in the field of groundwater management and numerical modeling: Dr. John Bredehoeft (United States Geological Survey), Dr. Steve Gorelick (Stanford University), and Dr. Shlomo Neuman (University of Arizona). Members of the GWTAC met with the project team several times during the course of the project to discuss methodology and results. After each of these meetings, recommendations from the GWTAC members were incorporated into the model. Appendix A summarizes the major concerns of the GWTAC members, and discusses how each of their concerns was incorporated into the groundwater model

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construction and calibration. At the completion of the model development, calibration, and verification, the GWTAC members were satisfied that the model met the standards of scientific and engineering practice, and provided the District and City with a good tool to further evaluate operation of the Santa Clara Valley Groundwater Basin. The GWTAC members emphasized, however, that the continued usefulness of the model depended on its continual improvement by incorporating additional data and undertaking additional analyses.

The numerical model is accompanied by: a data base and geographic information system (GIS) (CH2M HILL, 1992b); a technical memorandum about site-specific recharge feasibility (CH2M HILL, 1992c); a subsidence threshold report (GEOSCIENCE Support Services, 1991); and a memorandum about the estimated operational basin storage (CH2M HILL, 1991).

Following this introductory section, Section 3 summarizes data available for the numerical model and general assumptions made to construct, calibrate, and verify the model. Section 4 discusses model construction. Section 5 presents results of groundwater model calibration (including changes to the original conceptual model) and verification. Section 6 includes recommendations for further refinement of the numerical model and additional investigations that would support the model.

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2.4 Study Area

The numerical model was built to simulate groundwater flow in the alluvial basin north of Coyote Narrows and within SCVWD boundaries. As shown on Figure 2-1, the study area boundaries were:

- The edge of the Santa Clara Valley Basin alluvial fill as delineated by the SCVWD
- The boundary at Coyote Narrows between Santa Clara Valley Basin and Coyote Basin in southern Santa Clara Valley
- The boundary between Santa Clara County and San Mateo and Alameda Counties; this is the northern SCVWD boundary and it includes the southernmost portion of the Fremont groundwater basin

As needed during the construction, calibration, and verification of the model, the study area was extended beyond these boundaries. For example, the surrounding watershed areas were included in the water balance analysis, and additional portions of the Fremont groundwater basin were included in the numerical model.

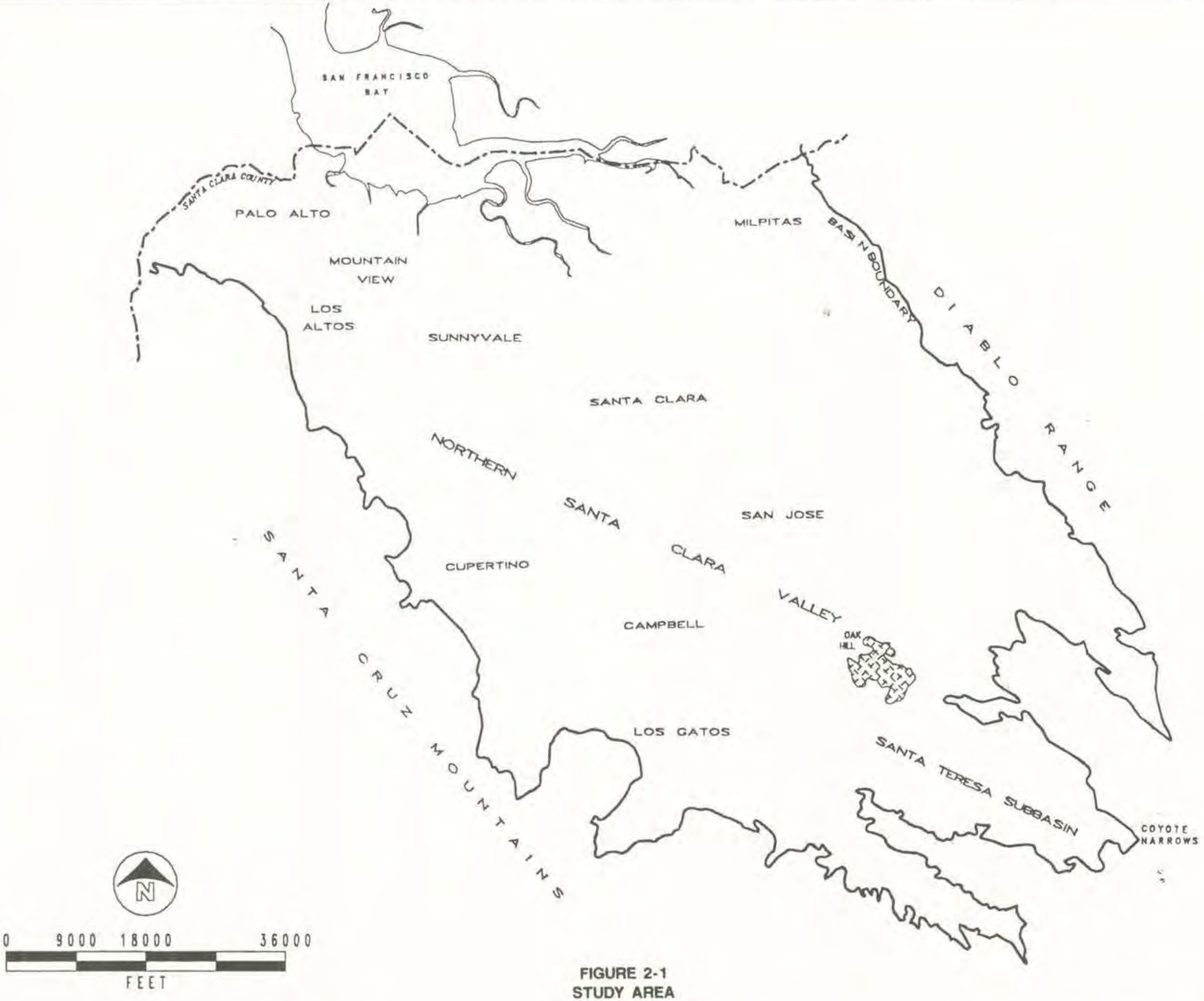

FIGURE 2-1
STUDY AREA

Section 3

Numerical Flow Model Selection and Available Data

The numerical model was intended to simulate basinwide groundwater flow in the Santa Clara Valley Basin. This section reviews the selection of the numerical model, and the data available for subsequent model construction, calibration, and verification.

3.1 Model Selection

After reviewing the capabilities and availability of many codes, CH2M HILL recommended that the SCVWD and the City of San Jose consider two models: MODFLOW and CFEST. MODFLOW is the popular three-dimensional finite difference groundwater flow code developed by the USGS (McDonald and Harbaugh, 1988). CFEST is a common finite element flow and transport model developed at Battelle Northwest Laboratory by S. Gupta et al. (1980). Table 3-1 summarizes the advantages and limitations of each code.

The SCVWD and the City of San Jose selected MODFLOW to simulate groundwater flow conditions for this project. Although potentially not as flexible as CFEST, MODFLOW has the advantage of being familiar to a number of groundwater professionals and is widely supported.

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3.2 Available Data

Abundant data were required to construct, calibrate, and verify the Santa Clara Valley Basin numerical model. Data were needed to support the model boundaries and hydrogeologic parameters, as well as to describe the hydraulic response of the basin aquifers to stresses. The available data are presented in Section 3.2 of the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a). Table 3-2 presents a summary of the data needed to construct, calibrate, and verify the numerical model, as well as the data that are available from various sources.

Table 3-1
Comparison of Numerical Models

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	Models	
Attributes	**MODFLOW**	**CFEST (FE3DGW)**
Dimensionality	3-dimensional	3-dimensional
Solution technique	Finite difference	Finite element
Water table capability	Yes	Yes
Public domain	Yes	Yes
Ease of data input	Relative easy. Pre- and post-processors exist	More complicated. Pre- and post-processors exist.
Coordination with GIS or other graphics	Binary output files can be imported to other programs. USGS GIS interfaces may be available	CFEST/ARC-INFO link already developed for other CH2M HILL projects.
Computer compatibility	Runs on almost all computers	Will not run on PCs without substantial modification. Originally written for VAX computers. Unknown if an HP version exists.
Type of documentation	Open File Report 83-875	Battelle Memorial Institute publication BMI/ONWI-660
Is support available?	Yes, through IGWMC	Yes, thorugh CH2M HILL
Is the model validated (well accepted)	Yes	Yes
Contaminant transport	Add on program (MT3D) available from SS Papadopulos. Uses a modified MOC approach	Yes, solute and heat transport
Subsidence	Yes	Not currently available
Comments	Probably the most commonly used numerical model. Very well accepted.	--

Table 3-2
Summary of Available Model Input Data

Data Needed	Data Maintained by SCVWD	Additional Data Available from Other Sources
Well Location and Completion Information	1. Locations for up to 6,000 wells within the basin 2. Well completion information not available for all wells	--
Depth-Specific Water Levels	1. Water levels measured by retailers from production and monitoring wells (no standard frequency) 2. September and October water level data compiled into an annual interpreted, composited piezometric surface map	--
Lithologic Data	1. Lithologic data available for some of the 6,000 wells 2. Interpretive cross sections from previous studies	Consultant reports for local groundwater contamination sites (Figure 3-3)
Groundwater Pumping	Semi-annual (June and December) records of cumulative pumping on either well-by-well or wellfield-by-wellfield basis	Monthly pumping from water retailers
Aquifer Property Estimates (K_h, K_v, S)	1. Limited number aquifer tests (CH2M HILL, 1992a) 2. Specific Capacity Tests (Wood, 1967; CDWR, 1975; SCVWD, 1971; and Kimmel, 1986)	1. Finite element model of Middlefield/Ellis/Whisman (MEW) groundwater contamination site in Mountain View (NPL sites 34, 59, and 102 on Figure 3-3; CDM, 1989) 2. Finite difference model of Santa Teresa Basin (Woodward-Clyde Consultants, 1988)
Facility Recharge Estimates	Monthly facility-specific estimates (23 facilities) based on BNDFLO program (Majumdar, et al. 1977; Galvan, et al, 1981; and Finnemore, 1987) for 1967-1990	--
Rainfall Infiltration	Estimated in SCVWD annual reports (Figures 3-1 and 3-2) and previous modeling studies	--
Streambed Recharge/Discharge		
Evaportranspiration		
Deep Percolation of Delivered Water		
Estimates of Groundwater Flow across Model Boundaries		

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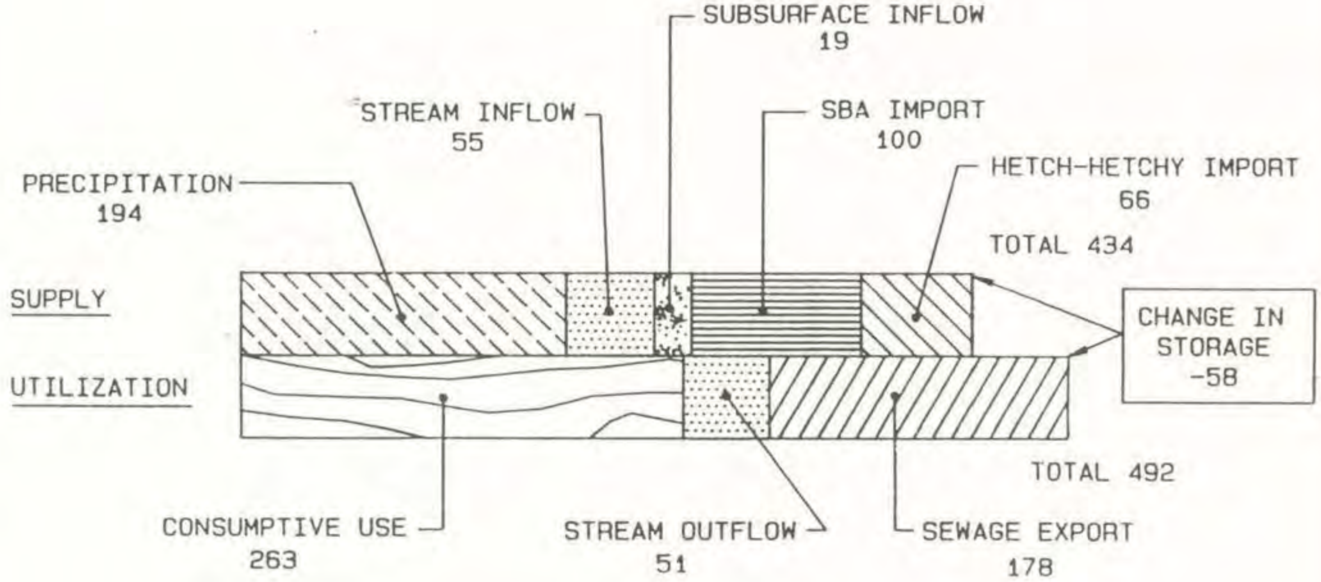
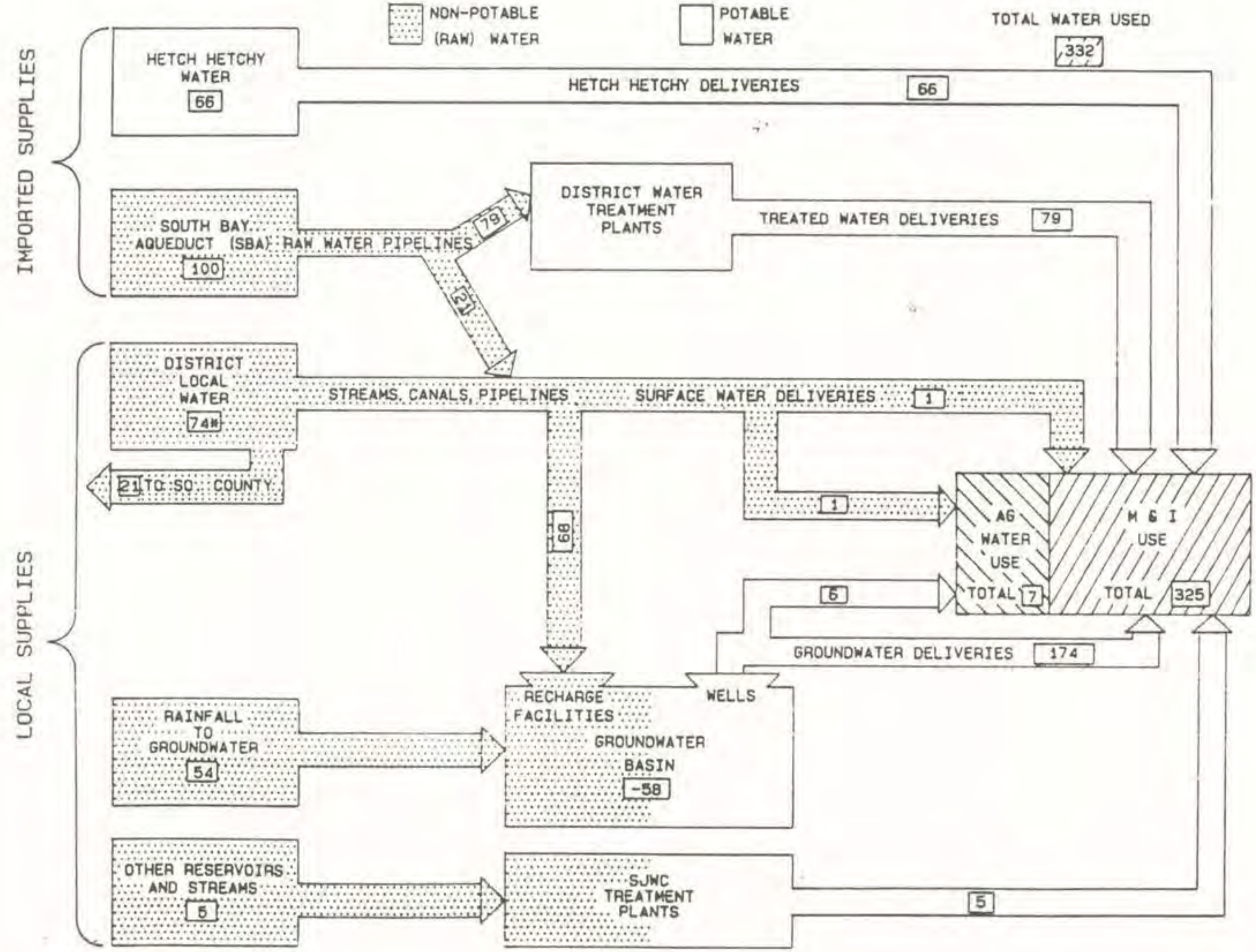


VALUES IN THOUSANDS ACRE-FEET
SBA=SOUTH BAY AQUEDUCT

FIGURE 3-1
HYDROLOGIC BALANCE OF SANTA CLARA VALLEY GROUNDWATER BASIN, 1984-1985

SOURCE: SCVWD, 1985



*INCLUDES 70 THOUSAND ACRE-FEET FROM RESERVOIRS; 40 THOUSAND ACRE-FEET STORED IN PREVIOUS YEARS, AND 4 THOUSAND ACRE-FEET FLOW TO SAN FRANCISCO BAY.

SOURCE: SCVWD, 1985

FIGURE 3-2
SANTA CLARA VALLEY BASIN
WATER SUPPLY AND USE 1984-1985

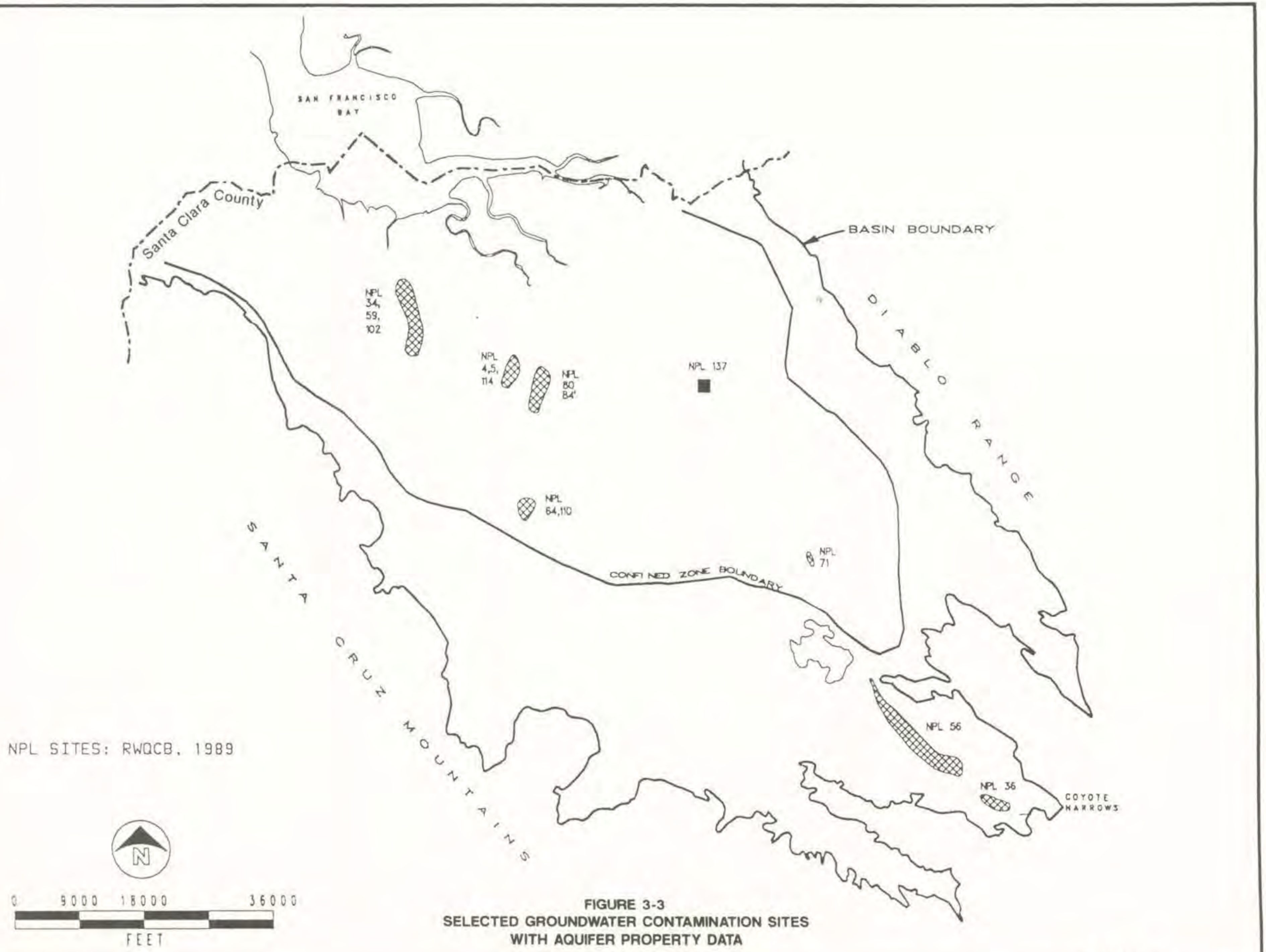


FIGURE 3-3
SELECTED GROUNDWATER CONTAMINATION SITES
WITH AQUIFER PROPERTY DATA

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Section 4
Numerical Model Construction

The numerical groundwater flow model incorporates the conceptual model presented in the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a). The purpose of this section is to describe how the data presented in that memorandum, and the data and assumptions discussed in Section 3.2, were incorporated into the numerical model of the Santa Clara Valley Basin.

4.1 Model Assumptions

Numerical models are necessarily approximations of natural systems. Simplifying assumptions are required to reduce natural complexities into a readily analyzed problem. The assumptions should simplify the model, while maintaining enough complexity to adequately reproduce the system behavior (Anderson and Woessner, 1992). Additionally, certain assumptions are necessary to balance the effort expended to set up the model and the accuracy and usefulness of the model's results. The most important assumptions are listed below, and each assumption is explained in more detail in the following paragraphs.

- Although the basin consists of complexly interfingered sediments deposited by coalescing alluvial fans, general lithologic patterns can be used to define hydrogeologic zones.
- Simulating every pumping well is unnecessary; accounting for at least 95 percent of all groundwater pumping is sufficient.
- The "confined zone" follows a boundary described by the SWRCB (1955). Wells outside this confined zone boundary display unconfined conditions.
- No streambed recharge or discharge occurs in the confined zone.
- The Evergreen subbasin (Figure 2-1) is sufficiently separate hydrologically from the main basin that it need not be modeled.

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4.2 Model Grid

Figure 4-1 shows the finite difference model grid on which the numerical model was built. The grid comprises 57 rows and 92 columns. Active grid nodes encompass an area of approximately 315 square miles (active nodes are identified by model layer in Figures 4-2 through 4-6). The grid is oriented sub-parallel and perpendicular to the predominantly northwesterly groundwater flow direction estimated from the SCVWD's annual piezometric surface maps (see, for example, Figure 4-7). Because groundwater generally recharges along mountain fronts and flows along the basin's longitudinal axis, the grid is sub-parallel to the longitudinal axis of the Santa Clara Valley Basin.

Grid discretization was made finest near apparent drawdown cones shown on the annual piezometric surface maps, generally near downtown San Jose, where grid cells are 1,000 feet on a side. The largest cells, under San Francisco Bay, are 6,000 feet on a side. To reduce numerical errors caused by discretization of the basin, cell lengths were always less than 1.5 times the length of any neighboring cell.

4.3 Model Layers

To represent the multiple piezometric heads, the hydrostratigraphic complexity and the three-dimensional groundwater flow in the Santa Clara Valley Basin, the numerical model was divided into several layers. Previous attempts to divide the basin into layers, and the current layering, are described below.

4.3.1 Previous Studies

Previous studies have noted the hydrostratigraphic complexity and heterogeneity of the Santa Clara Valley Basin. Poland (1962), when discussing sand and gravel deposits, noted that "...none of the deposits can be traced more than a short distance...," and cross sections developed by the RWQCB/SEEHRL/SCVWD (1985) and CDWR (1975) depict the basin as a sequence of semi-continuous or discontinuous high-conductivity zones, surrounded by a low-conductivity matrix.

Authors of previous models of the Santa Clara Valley Basin have conceptualized the basin as more than one layer to account for the multiple piezometric surfaces (CDWR, 1975; CDWR, 1985; Reichard and Bredehoeft, 1984). In the previous models, the authors generally divided the groundwater basin into three layers: an upper unconfined layer, a confining layer, and a single lower confined layer.

The CDWR studied water levels collected in spring of 1963, and concluded that at least four separate piezometric surfaces existed in the basin (CDWR, 1967). The same report notes, "...wells in the San Jose subarea often display different water levels, even in wells only a few feet apart." These multiple piezometric surfaces suggest that more than three model layers may be necessary to adequately represent the basin's hydrogeology.

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4.3.2 Current Interpretation

Based on the results of previous work and on available data, the framework of the numerical model described in this report consists of three general hydrogeologic units: an unconfined unit, a confining unit, and a confined unit. The depths of the unconfined unit and the confining unit were based on lithology; these units translate to Model Layers 1 and 2, respectively. To account for the multiple piezometric surfaces and vertical gradients within the confined unit, however, three model layers were defined to represent the confined unit (Model Layers 3, 4, and 5). The depths of the model layers within the confined unit were based on the incidence of well perforations, as discussed in Section 4.2.2.1 of the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a). A sixth model layer was added to account for the aquifer below the existing production wells.

Depths to the bottom of each model layer were estimated from available well perforation data for the 13 subareas used in the well perforation analysis. These depths were assigned to a point near the geographic center of each subarea and to additional control points along the basin boundary. Layer-bottom surfaces were then interpolated from these control points at each cell center. Figure 4-8 shows the locations of the control points used for the model layer interpolations.

The active portion of the model grid does not extend to the basin boundary in all layers. Active cells in Model Layers 1 and 2 extend only to the confined zone boundary. Model Layer 3, which is confined in the center of the basin, acts as the upper, unconfined unit in the Santa Teresa Basin and near the borders of the basin. This configuration was adopted to represent the groundwater flow passing from the recharge zone into the deeper portions of the confined zone. Model Layers 4, 5, and 6 do not extend to the edges of the basin because bedrock is encountered at depth. Figure 4-9 presents a schematic cross-section of the model layers from the northwest to the southeast. The location of the cross section is shown on Figure 4-10. Figures 4-2 through 4-6 show the areal extent of the active nodes in each model layer.

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4.4 Model Boundaries

Boundary conditions are specified for all sides and the top and bottom of the numerical model. Boundary conditions along the sides of the model are designated explicitly by the model input; boundary conditions along the top and bottom surfaces of the model are controlled by layer definition.

Horizontal model boundaries are controlled by cell type. In MODFLOW, three cell types are allowable: active cells, inactive cells, and constant head cells. Groundwater flow equations are solved for active cells, but are not solved for inactive cells.

Because no groundwater flows into or out of inactive cells, the cell face between an active and inactive cell represents a no-flow boundary. Constant head cells allow groundwater to flow into or out of the cell; the pressure, however, is fixed. Constant head cells are often used to represent large bodies of water that have known water levels, such as lakes and bays.

Figures 4-2 through 4-6 display the cell types in each model layer for the upper five model layers. Active cells in Model Layers 1 and 2 exist only within the confined zone. As mentioned in Section 4.2, flow in the upper aquifers outside the confined zone is simulated by Model Layer 3 to represent the dominant flow of groundwater from the margins of the basin into the deeper portions of the confined zone. The extent of the active cells in Model Layers 3, 4, and 5 represents the assumed boundary between active aquifers and surrounding bedrock at various depths. These boundaries were based on deep boreholes and geophysical studies (CDWR, 1967; Hazlewood, 1976; Robbins, 1969).

Model Layer 6 functions as a buffer between Model Layer 5 and the bedrock bottom of the basin. The depth of sediments near the center of the basin is unknown; therefore, Model Layer 6 was introduced to account for any deep circulation of groundwater beneath Model Layer 5. The extent of Model Layer 6 matches the extent of Model Layer 5, and cell type designations for Model Layer 6 are identical to the cell type designations of Model Layer 5 (see Figure 4-6).

The collection of constant head cells in the northwest corner of Model Layer 1 simulate San Francisco Bay. The hydraulic head in these cells is set at zero feet mean sea level (ft msl). Constant head cells in Model Layer 1 include tidal lowlands south of San Francisco Bay. The southern extent of these tidal lowlands is based on the distribution of recent Bay Mud, mapped by Helley and Lajoie (1979).

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A line of constant head cells under San Francisco Bay defines the northwest boundary of the model in Model Layers 2 through 5 (Figures 4-3 through 4-6). These constant head cells represent deep zones with little suspected groundwater circulation between aquifers of the Santa Clara Valley Basin and the Fremont groundwater area. Relatively little is known about the aquifers beneath San Francisco Bay. To prevent boundary effects in the groundwater flow model, the constant head cells that represent the boundary with the Fremont groundwater area are located several miles northwest of the actual boundary location.

One other set of constant head cells represents the Coyote Narrows in Model Layer 3 (Figure 4-4, lower right hand corner). Discussions with SCVWD staff (Iwamura, 1991) indicated that the groundwater table near the Coyote Narrows generally remains close to ground surface because of the volume of water that passes through the narrow gap. A constant head elevation of approximately 230 feet above msl was assigned to the three model cells that represent the Coyote Narrows. This groundwater elevation is based on water table maps produced by the SCVWD and Woodward-Clyde Consultants (1990).

4.5 Aquifer Parameters

In finite difference models, aquifer parameters (horizontal and vertical hydraulic conductivities, transmissivities, and storage coefficients) are assigned to each cell in the model grid of each layer. Initial estimates of these parameters are based on available data and are subsequently adjusted during calibration to help fit model results to known data. Models with good predictive ability generally incorporate a small number of aquifer parameters (Freyberg, 1988). The number of parameters is kept small by replacing individual values at every cell with an average parameter for a group of hydrogeologically similar cells. A group of model cells with the same calibration parameter value constitute a parameter zone.

Parameter zones are based on the distribution of parameter measurements, or other measurements that indirectly control a parameter value. Available data are incorporated into the model with discretion based on such factors as data quality. For example, aquifer test results, specific capacity data, lithologic data, and general piezometric surface features may be used to define zones of horizontal hydraulic conductivities in various model layers. The aquifer test results, however, will likely influence the conductivity zonation more than piezometric surface features, because aquifer test results are direct estimates of hydraulic conductivity.

The following sections discuss how aquifer parameter values were incorporated into the numerical model.

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4.5.1 Horizontal Hydraulic Conductivity and Transmissivity

The horizontal hydraulic conductivity distribution of the Santa Clara Valley Basin aquifers was grouped into 11 zones based on the conceptual model presented in the Draft Hydrogeologic Interpretation Technical Memorandum (CH2M HILL, 1992a). The parameter values for each zone were based on aquifer test results, specific capacity data, lithologic data, and general piezometric surface patterns. Transmissivity values for model layers that require transmissivity as input were then calculated by multiplying the hydraulic conductivity value by the model layer thickness.

Specific capacity data for approximately 320 wells were collected from SCVWD files; of these, well completion information was available for approximately 178 wells. The specific capacity data for the 178 wells are listed in Appendix B. The 178 specific capacity values were then assigned to model layers based on the perforated interval of the well. For wells that were perforated across more than one model layer, the percentage of the total specific capacity assigned to a model layer was equivalent to the percentage of total well screen that fell within the model layer. This method of dividing specific capacity among layers assumes that drillers successfully perforate only highly transmissive zones, that drillers successfully perforate all highly transmissive zones, and that all perforated zones in a single well have an equivalent horizontal hydraulic conductivity. Model layers that include less than 15 percent of a well's total perforated length are not assigned a specific capacity from that well (to prevent assigning probably unrepresentative small specific capacities to model layers where the bottom of a well penetrated only a small portion of the model layer). Figures 4-11 through 4-13 present available specific capacity values available for Model Layers 3 through 5. Model Layers 1 and 2 had too few specific capacity data to produce reasonable maps.

4.5.1.1 Model Layers 1 and 2

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Because few specific capacity data were available for Model Layers 1 and 2, initial values of horizontal hydraulic conductivity for Model Layers 1 and 2 were obtained from shallow aquifer tests conducted at groundwater contamination sites, and from the calibrated model of the Middlefield/Ellis/Whisman (MEW) site (NPL Sites 34, 59, and 102; Figure 3-3; CDM, 1989). Horizontal hydraulic conductivities measured at hazardous waste sites ranged from $3.3x10^{-4}$ to 240 feet per day (ft/day) (CH2M HILL, 1992a). Model Layers 6 through 10 of the MEW model roughly correspond to the basinwide Model Layer 1, and Model Layers 3, 4, and 5 of the MEW model roughly correspond to the basinwide Model Layer 2. Geometric averages of the horizontal hydraulic conductivities from the MEW model are about 10 ft/day for MEW Model Layers 6 through 10, and about 4 ft/day for MEW Model Layers 3 through 5. The initial horizontal hydraulic conductivity distribution for Model Layers 1 and 2 is presented on Figures 4-14 and 4-15.

4.5.1.2 Model Layers 3, 4, and 5

Specific capacities for wells in Model Layers 3 through 5 ranged from less than 1 gallon per minute per foot of drawdown (gpm/ft) to 263 gpm/ft. The noticeable high specific capacity bullseyes on Figures 4-11 through 4-13 are the result of available data: either data are missing from other, unknown high specific capacity zones because no wells have been drilled there; or existing wells are located in their current location because, through past experience, water retailers and drillers know the locations of the best producing aquifers. Based on the long history of water development in the Santa Clara Valley Basin, the bullseyes likely represent the most productive areas.

Specific capacity values were multiplied by 2,000 to provide a rough estimate of transmissivities in units of gallons per day per foot for Model Layers 3, 4, and 5 (Driscoll, 1986). The aforementioned specific capacities result in transmissivities ranging from 2,000 to 526,000 gallons per day per foot. Dividing transmissivities by the thickness of the model layer resulted in a set of horizontal hydraulic conductivities, distributed in the same bullseye fashion as the specific capacities.

Initial horizontal hydraulic conductivity values were assigned to the conductivity zones delineated in the conceptual model by overlaying the specific capacity maps on the interpreted hydrostratigraphic maps presented in Section 4.2.2.2 of the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a). The initial horizontal hydraulic conductivity distribution for Model Layers 3, 4, and 5 are presented on Figures 4-16, 4-17, and 4-18.

No specific capacity data were available for Model Layer 6. We assumed that wells completed in Model Layer 5 were stopped when a low-permeability unit was encountered, indicating that Model Layer 6 can be treated as a moderately low-permeability unit. Therefore, a uniform transmissivity of 20 ft_2/day was initially assigned to Model Layer 6.

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4.5.1.3 Santa Teresa Basin

The horizontal hydraulic conductivity zones and values for the Santa Teresa Basin were obtained from the calibrated numerical model of groundwater flow for the Edenvale Wellfield (Woodward-Clyde Consultants, 1988). Transmissivity values from the lower model layer of the Woodward-Clyde Consultants model were superimposed on the numerical model grid and divided by saturated thickness to obtain horizontal hydraulic conductivity estimates.

4.5.2 Vertical Hydraulic Conductivity

Vertical hydraulic conductivity values were estimated for the basin, and leakance was calculated using formulas in the MODFLOW User's Manual (McDonald and Harbaugh, 1988).

Table 4-1 lists available vertical hydraulic conductivity data for the Santa Clara Valley Basin.

Table 4-1
Available Vertical Hydraulic Conductivity Data

Approximate Depth (Below Ground Surface)	Measurement Method	Vertical Hydraulic Conductivity (ft/day)	Source
Upper 20 feet	Aquifer test	1.0	Hamlin (1983)
Upper 45 feet	Aquifer test	4.28×10^{-3}	Sheahan (1977)
0 to 1000 feet	Laboratory	9×10^{-6} to 4×10^{-3}	Johnson et al. (1968)
0 to 400 feet (Santa Teresa)	Calibrated Model	0.12 to 1.2	Woodward-Clyde (1988)
0 to 1000 feet	Calibrated Model	1×10^{-4} to 2.0	CDM (1989)

Initial estimates of vertical hydraulic conductivities for Model Layers 1 and 2 were derived from the MEW model (CDM, 1989). Using the harmonic average of vertical hydraulic conductivities used in the MEW model, an initial estimate of 3.0×10^{-2} feet/day was assigned to Model Layer 1, and an initial estimate of 1.8×10^{-3} feet/day was assigned to Model Layer 2.

Assuming that similar lithologic zones have uniform vertical as well as horizontal hydraulic conductivities, vertical hydraulic conductivity zones for Model Layers 3, 4, and 5 were initially assigned identically to the horizontal hydraulic conductivity zones for the same model layers. The value of vertical hydraulic conductivity for each zone was then initially set at one tenth of the horizontal hydraulic conductivity value.

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4.5.3 Storage Coefficient

Two types of storage coefficients were assigned to numerical model cells: storativity (for confined and semi-confined conditions) and specific yield (for unconfined conditions). Available storativity estimates are presented in Table 4-2. As shown, the available storativity estimates range from 2.6×10^{-1} to 3.6×10^{-5}. An initial storativity of 1.0×10^{-4} was assigned to all confined model layers.

The CDWR estimated specific yields based on lithologic logs (CDWR, unpublished). Specific yields were assigned to drillers' calls, and a depth-averaged specific yield was assigned to different areas of the basin. CDWR's specific yield estimates for the Santa Clara Valley Basin are shown on Figure 4-19, and range from 0.035 to 0.11 (CDWR, unpublished). Based on the data contained on Figure 4-19, an initial specific yield estimate of 0.07 was assigned to all unconfined model layers.

Table 4-2
Available Storativity Estimates

Location	Storativity	Reference
Well 06S1E31K01	2.8×10^{-2}	SCVWD, 1971
Well 07S1E02J06	4.2×10^{-4}	SCVWD, 1971
Well 07S1E07R04	1.9×10^{-3}	SCVWD, 1971
Well 07S1E22H04	8.0×10^{-4}	SCVWD, 1971
Well 07S1E29A01	6.7×10^{-2}	SCVWD, 1971
Well 07S1E29A02	1.5×10^{-3}	SCVWD, 1971
Well 07S1W13E04	5.0×10^{-5}	SCVWD, 1971
Well 07S1W22E11	2.9×10^{-4}	SCVWD, 1971
Well 07S1W23R01	4.3×10^{-2}	SCVWD, 1971
Well 07S1W24J02	1.2×10^{-2}	SCVWD, 1971
Well 08S1E05H07	3.2×10^{-2}	SCVWD, 1971
Well 08S1E10K03	1.0×10^{-2}	SCVWD, 1971
Palo Alto, 185-foot aquifer	2.0×10^{-3}	Sheahan, 1977
Palo Alto, 45-foot aquifer	3.6×10^{-5}	Sheahan, 1977
Palo Alto, 20-foot aquifer	2.0×10^{-3}	Sheahan, 1977
Palo Alto, Upper Aquifer	2.0×10^{-3}	Hamlin, 1983
Palo Alto, Lower Aquifer	5.0×10^{-4}	Hamlin, 1983
Groundwater Remediation Sites	1.1×10^{-5} to 2.6×10^{-1}	Beak Consultants, 1990; Canonie, 1986, 1988; EMCON, 1988; Engineering Science, 1985; Geosystem Consultants, 1991; Harding Lawson, 1988, 1990; Woodward-Clyde, 1988

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4.6 Groundwater Balance Components

The general groundwater balance for the Santa Clara Valley Groundwater Basin was presented in Section 4.3 of the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a). The following paragraphs present how the general groundwater balance was incorporated into the numerical model.

4.6.1 Basin Discharge

Groundwater pumping by municipalities, private water retailers, and industry accounts for the majority of the groundwater basin discharge. Minor components include underflow beneath the San Francisco Bay, evapotranspiration, sewer gains, and discharge to gaining streams.

4.6.1.1 Major Components

Groundwater pumping was incorporated into the numerical model through model nodes (each node defined by a row, column, and layer designation) that contain pumping wells. As noted previously, although the SCVWD maintains pumping records on approximately 6,000 wells, well completion data (needed to assign the pumping to model layers) were not available for all wells. Therefore, a method to account for a majority of the pumping and distribute the pumping across model layers was designed; the product was a pumping wells data base.

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To reduce the number of wells in the pumping wells data base to a manageable number, all wells with recorded pumping during a specific quarter (for instance, 4th quarter, 1980) were ranked from smallest quantity pumped to largest quantity pumped. The cumulative pumping was then plotted against the number of wells contributing to the cumulative pumping (see Figure 4-20, for example). A graph of cumulative pumping versus number of wells was produced for each year between 1970 and 1990. These graphs revealed that 95 percent of the total pumping in every quarter between 1970 and 1990 could be accounted for with 1,036 wells. Assuming that the remaining 5 percent of the pumping is from small domestic or agricultural wells that do not greatly influence groundwater flow directions on a regional scale, 95 percent was adopted as the amount of pumping that would be accounted for during calibration and verification. All wells that comprised 95 percent of the pumping from any one quarter were included in the pumping wells database.

Pumping from each well in the pumping wells database was assigned to model layers based on the percent of the well's total perforated length that crossed each model layer. For example, if 30 percent of a well's total perforated length crossed Model Layer 4, then 30 percent of the pumping from that well was assigned to Model Layer 4. For wells for which no completion information was available, completion information from nearby wells that pumped water for similar purposes was used. Figure 4-21 shows the location of all pumping wells used to calibrate the numerical model.

Pumping data available from the SCVWD are for 6-month time periods. To model shorter stress periods, these pumping data were divided into monthly intervals using monthly pumping data supplied by the water retailers. The retailers' pumping data were first grouped into 6-month totals that matched the SCVWD's pumping data. Total retailer pumping for each month was then compared to total retailer pumping for the corresponding 6-month total. Assuming that all wells are pumped according to a similar pumping pattern, the 6-month pumping totals were divided into monthly units using the same proportions as the retailers' pumping.

4.6.1.2 Minor Components

Groundwater discharge by evapotranspiration is accounted for in the numerical model by subtracting it from the areal recharge matrix. Because agricultural and municipal evapotranspiration is already considered in the estimates of return flow, only willows growing along the banks of streams were included in the evapotranspiration calculations. Willows were assumed to grow along the banks of all recharging streams, for 50 feet on either side of the stream. Evapotranspiration by willows is approximately 50 inches per year (Davis and DeWiest, 1966). Model cells that simulated evapotranspiration are shown on Figure 4-22.

No data exist to estimate groundwater discharge to gaining streams. Groundwater discharge through artesian wells was considered insignificant and was not estimated.

Groundwater lost through sewer infiltration has been estimated at 5,601 acre-feet per year for sewer lines servicing the San Jose Wastewater Treatment Plant (CH2M HILL, 1992d; Esmay, 1992). The areal distribution of sewer infiltration has not been determined; therefore, sewer infiltration was uniformly distributed throughout the basin. Infiltration estimates for sewer lines servicing the Palo Alto and Sunnyvale treatment plants were not estimated.

Groundwater lost through underflow beneath San Francisco Bay is poorly understood. The underflow beneath San Francisco Bay is not explicitly entered into the recharge matrix. The model includes a prescribed head boundary condition beneath San Francisco Bay, and the model calculates the flow necessary to maintain the prescribed head.

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4.6.2 Basin Recharge

Components of recharge to the groundwater basin include: underflow from adjacent basins; infiltration of excess precipitation; recharge through SCVWD facilities; subsurface inflow from bedrock; inflow from gaged and ungaged streams; deep percolation of delivered municipal and industrial (M&I) water; and deep percolation of agricultural water, pipeline losses, sewer losses, and septic tank leachate. Figure 4-23 illustrates how available data are used to estimate the various recharge components. The following paragraphs explain how each component is estimated.

To estimate infiltration from rainfall, seven rainfall zones that cover the Santa Clara Valley were delineated based on an isohyetal map provided by the SCVWD (1988). Model cells corresponding to each rainfall zone (and the annual precipitation for each zone) are displayed on Figure 4-24. Quarterly rainfall for each zone was estimated by weighing quarterly rainfall from two National Oceanic and Atmospheric Administration (NOAA) climatic stations: San Jose and Los Gatos 4.

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The general equation for estimating rainfall in a rainfall zone is:

$$RF_z=[(F_{sj})x(RF_{sj})x(\frac{Avg_z}{Avg_{sj}})]+[(F_{lg})x(RF_{lg})x(\frac{Avg_z}{Avg_{lg}})]$$

Where:

RF_z = Quarterly rainfall on zone Z.

F_{sj} = A location factor describing the relative influence of the San Jose weather station on zone Z. This factor is 1.0 for the rainfall zone that includes San Jose, and 0.0 for the rainfall zone that includes Los Gatos. The factor is a fraction for rainfall zones between San Jose and Los Gatos.

RF_{sj} = Quarterly rainfall at the San Jose weather station.

Avg_z = One quarter of the average annual rainfall on zone Z.

Avg_{sj} = One quarter of the average annual rainfall at San Jose.

F_{lg} = A location factor describing the relative influence of the Los Gatos weather station on zone Z. This factor is 1.0 for the rainfall zone that includes Los Gatos, and 0.0 for the rainfall zone that includes San Jose. The factor is a fraction for rainfall zones between San Jose and Los Gatos.

RF_{lj} = Quarterly rainfall at the Los Gatos weather station.

Avg_{lg} = One quarter of the average annual rainfall at Los Gatos

Rainfall-recharge relationships have not been developed from data available from the Santa Clara Valley. Empirical relationships, therefore, are necessary to estimate the relationship between rainfall and deep percolation. The relationship applied to quarterly rainfall to obtain quarterly percolation for the groundwater model was:

$$\text{Percolation} = 0.1 \times (\text{Rainfall})^2$$

where percolation and rainfall are both measured in feet. The rainfall-recharge relationship is graphed in Figure 4-25. Included on Figure 4-25 are the average annual recharge amounts, and the maximum quarterly recharge amounts. The average annual recharge amounts are 0.95 inches and 2.63 inches for San Jose and Los Gatos, respectively. These recharge rates are comparable to the 2.4 inches per year assumed for the Fremont area by CDWR (1968), and considerably less than the 6.95 inches assumed in the Edenvale Wells Hydrology Technical Report (Woodward-Clyde, 1988).

The rainfall-recharge relationship in Figure 4-25 is ever-increasing, and therefore may over-estimate recharge from severe rainfall events. Although the rainfall values derived from this graph do not appear excessive, a more realistic rainfall-recharge relationship might reflect the fact that soils have a finite capacity for recharge. When a soil nears its maximum recharge capacity, additional rainfall produces insignificant recharge. The resulting rainfall-recharge relationship would assume a sigmoid shape.

The rainfall-recharge relationship is applied uniformly throughout the basin, regardless of land use. Highly developed municipal and industrial areas likely receive less percolation from rainfall than other areas. Therefore, this rainfall-recharge relationship may over-estimate percolation from rainfall in the more highly developed central portion of the Santa Clara Valley.

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The SCVWD operates 23 recharge facilities in the Santa Clara Valley Basin. The SCVWD does not measure recharge at each of these facilities directly, but rather estimates the recharge using the program BNDFLO (Majumdar et al., 1977; SCVWD, 1981; SCVWD, 1987). Recharge estimates produced by BNDFLO can vary by up to 36,000 acre-feet per year for a given year, depending on the assumptions incorporated into the calculations. The groundwater model was calibrated using BNDFLO assumptions that produce lower recharge values, referred to as the "limited recharge" assumptions. After calibration, a revised version of BNDFLO data was produced by the SCVWD, and these data were subsequently incorporated into the groundwater model. The revised BNDFLO version uses the "unlimited recharge" assumptions, but adjusts certain recharge facilities to prevent unrealistic amounts of recharge. Recharge estimates from BNDFLO are incorporated directly into the numerical model's areal recharge matrices. Recharge from streams is distributed to individual model cells based on the percentage of total stream length that passes through each cell. Similarly, recharge from ponds is distributed to individual cells based on the percentage of total pond area in each cell. Figure 4-26 displays model cells that are used to simulate recharge facilities.

Ungaged stream recharge (stream recharge not estimated by BNDFLO) was estimated for five streams in the basin: Permanente Creek, Hale Creek, Adobe Creek, Berryessa Creek, and Arroyo de las Coches. Estimates are based on the assumption that the amount of water available for recharge is directly proportional to the stream's catchment area. A proportionality constant was calculated for each of the five streams by comparing the stream's catchment area to that of a nearby, gaged stream; Permanente, Hale, and Adobe Creeks were compared to Stevens Creek, and Berryessa Creek and Arroyo de las Coches were compared to Penetencia Creek. Catchment areas for each of the streams in the Santa Clara Valley Basin were provided by the SCVWD (undated), and are included in Table 4-3. The recharge rate for each of the five ungaged creeks was estimated by multiplying the recharge from the appropriate gaged creeks (i.e., Stevens or Penetencia Creeks) by the proportionality constant specific to the ungaged creek.

Losses in the SCVWD transmission lines were estimated to be 8.0 percent although they could be as high as 9.5 percent (Yo, 1992). These losses are distributed along major SCVWD distribution lines, as shown on Figure 4-27. Losses to the groundwater from retailers' delivery systems were estimated at 8 percent (Schriber, 1992). Retailers' losses were distributed equally throughout the basin.

Deep percolation of applied waters (both agricultural and M&I) was estimated to be 20 percent of the water applied. It was assumed that all water delivered for agricultural purposes was applied to the ground. Flow at the SJ/SC WPCP comprises water that is not applied to the ground, plus water that has infiltrated into sewer lines from the ground. To calculate M&I applied water, the following formula was used:

$$\mathit{Applied\ Water} = (\mathit{Delivered\ Water}) - (\mathit{Flow\ at\ WPCP}) + (\mathit{Infiltration}) - (\mathit{Exfiltration})$$

Estimates of delivered water were derived from annual reports produced by SCVWD, less transmission losses as calculated above. Monthly flow data for the SJ/SC WPCP was supplied by the water pollution control plant. As mentioned earlier, the Sunnyvale and Palo Alto WPCPs were not included in this study. Infiltration was estimated in Section 4.6.1.2 of this report. Exfiltration from sanitary sewers servicing the SJ/SC WPCP was estimated to be 10 percent of the infiltration (Esmay, 1992). Based on the previous infiltration estimate of 5,601 acre-feet per year, exfiltration was set at 560 acre-feet per year.

Previous estimates of deep percolation of M&I applied water in the Santa Clara Valley were calculated by the California Department of Water Resources. The CDWR estimated deep percolation from the combination of rainfall and delivered M&I water for the years 1964 to 1970 (CDWR, 1975). Combining our estimates of deep

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Table 4-3
Drainage Areas

Drainage Area	Sub Area (sq.ml.)	Area (sq.ml.)
Scott Creek		0.91
Calera Creek		2.3
Between Calera Creek and Arroyo De Los Coches		1.2
Arroyo De Los Coches		3.4
Between Arroyo De Los Coches and Berryessa Creek		0.83
Berryessa Creek		4.5
Between Berryessa Creek and Penitencia Creek		1.7
Penitencia Creek		21.8
So. and W. of Penitencia Creek		1.1
North of Evergreen		5.2
Babb Creek	4.0	
Evergreen		22.3
Coyote		212.0
North of Anderson Dam	0.56	
North of USGS at Madrone to Metcalf Road	6.7	
North of Metcalf Road	4.4	
Anderson Reservoir	26.3	
Fisher Creek	5.8	
Metcalf Creek	0.83	
Los Animas	37.0	
Packwood Creek	10.1	
Coyote Reservoir	120.0	
Canoas Area		2.9
Almaden-Calero		30.4
South Side of Santa Teresa Hills	4.4	
Calero Reservoir	6.9	
Chilanian Gulch	0.66	
McAbee Creek	0.64	
South Side of Almaden Valley	4.6	
Below Almaden Dam to Station #16	0.05	
Almaden Reservoir	12.0	
Below Calero Dam to Station #13	0.22	
Inflow to Almaden-Calero Canal	0.92	

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Table 4-3
Drainage Areas

Drainage Area	Sub Area (sq.ml.)	Area (sq.ml.)
Guadalupe		13.8
Below Station #43	1.2	
Below Dam to Station #43	6.7	
Guadalupe Reservoir	5.9	
Los Gatos		42.1
Below USGS Station, and above Station #19	3.8	
Trout Gulch	1.4	
Above Lake Elsman	9.9	
Lexington Reservoir below Lake Elsman	27.0	
Ross Creek		2.8
Ross Creek	0.25	
Ross Creek below Station #21	0.65	
Ross Creek	1.9	
San Tomas Creek		3.2
Tributary to San Tomas Creek	0.94	
San Tomas Creek	2.3	
Saratoga Creek		9.8
South side of Saratoga Creek below USGS Station	0.3	
North side of Saratoga Creek below USGS Station	0.3	
Saratoga Creek above USGS Station	9.2	
Calabazas Creek		4.6
Calabazas Creek below Station #31	1.4	
Regnart Creek	0.5	
Calabazas Creek above Station #31	2.7	
Stevens Creek		21.0
Stevens Creek below Station #44	3.2	
Below Dam and above Station #44	0.79	
Stevens Creek Reservoir	17.0	
Permanente Creek		10.5
Permanente Creek	7.8	
Hale Creek	2.7	
Adobe Creek		7.3

Source: SCVWD, undated.

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percolation from rainfall and delivered M&I water yields a combined percolation of 3.61 and 7.63 inches from San Jose and Los Gatos, respectively, during 1969. The estimated combined percolation for 1970 are 3.65 and 5.38 inches for the same two stations. These numbers are comparable to urban recharge values displayed in Figure 13 of the CDWR report.

Subsurface inflows from bedrock and stream channels were combined into a single mountain-front recharge term. Estimation of mountain-front recharge is described in Section 4.3.1.5 of the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a). Mountain-front recharge values incorporated into the model along the Diablo Range, Silver Creek Ridge, and Santa Teresa Hills are the same as those calculated for the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a). Recharge along the front of the Santa Cruz Mountains was estimated at 1.0 inch per year, instead of the 1.5 inches per year listed in the Hydrogeologic Interpretation Draft Technical Memorandum. The resultant total mountain-front recharge incorporated into the groundwater model was 11,850 acre-feet per year, approximately 4,000 acre-feet per year less than the total mountain-front recharge listed in the Hydrogeologic Interpretation Draft Technical Memorandum. Mountain-front recharge for each mountain range was distributed across all cells bordering the mountain range, in proportion to the length of cell perpendicular to the mountains.

Septic tank discharges were considered insignificant and were not estimated in the recharge calculations. Losses from surface water deliveries to retailers were also considered insignificant, and were not included in the groundwater budget.

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4.7 Initial Head Distributions

Results of steady state simulations do not depend on initial head distributions. Therefore, to begin the steady state calibration, initial head distributions that mimicked ground surface elevations for each layer were used.

Initial head distributions for transient calibration were derived from water level data measured during late 1969 and early 1970 (the beginning of the transient calibration period; Section 5.1.1.2). Water level measurements recorded within 2 weeks on either side of January 1, 1970, were compiled, and assigned to model layers if possible. Data for Model Layer 3, which included the most water level data, were contoured to produce an initial head distribution. Initial head distributions for the other model layers were developed by starting with Model Layer 3 initial heads, and then adjusting the water levels upward or downward based on water level data of other layers. Figures 4-28 through 4-32 display the initial head conditions used in the transient simulations.

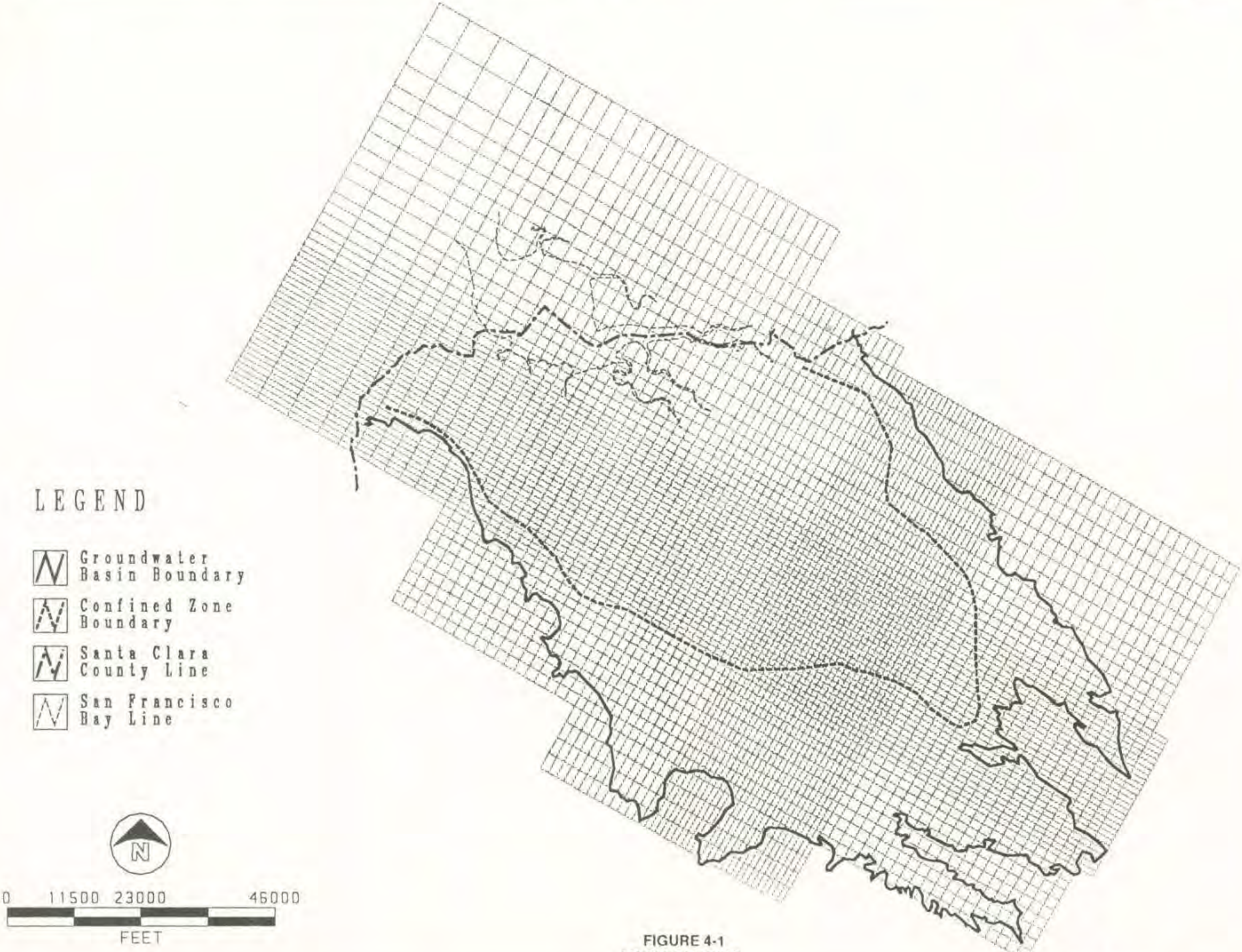


FIGURE 4-1
MODFLOW GRID

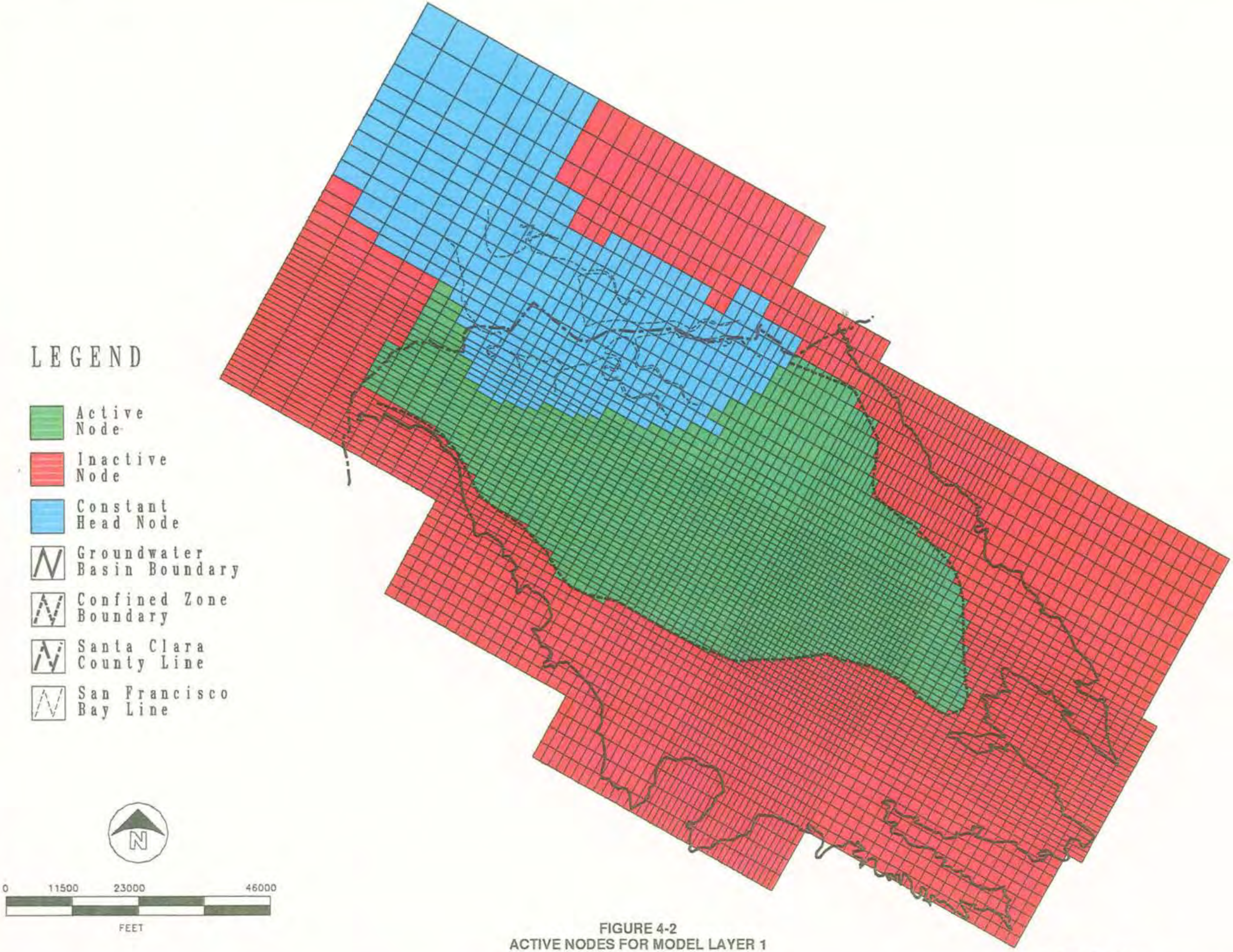


FIGURE 4-2
ACTIVE NODES FOR MODEL LAYER 1

CH2M HILL

October 12, 1992

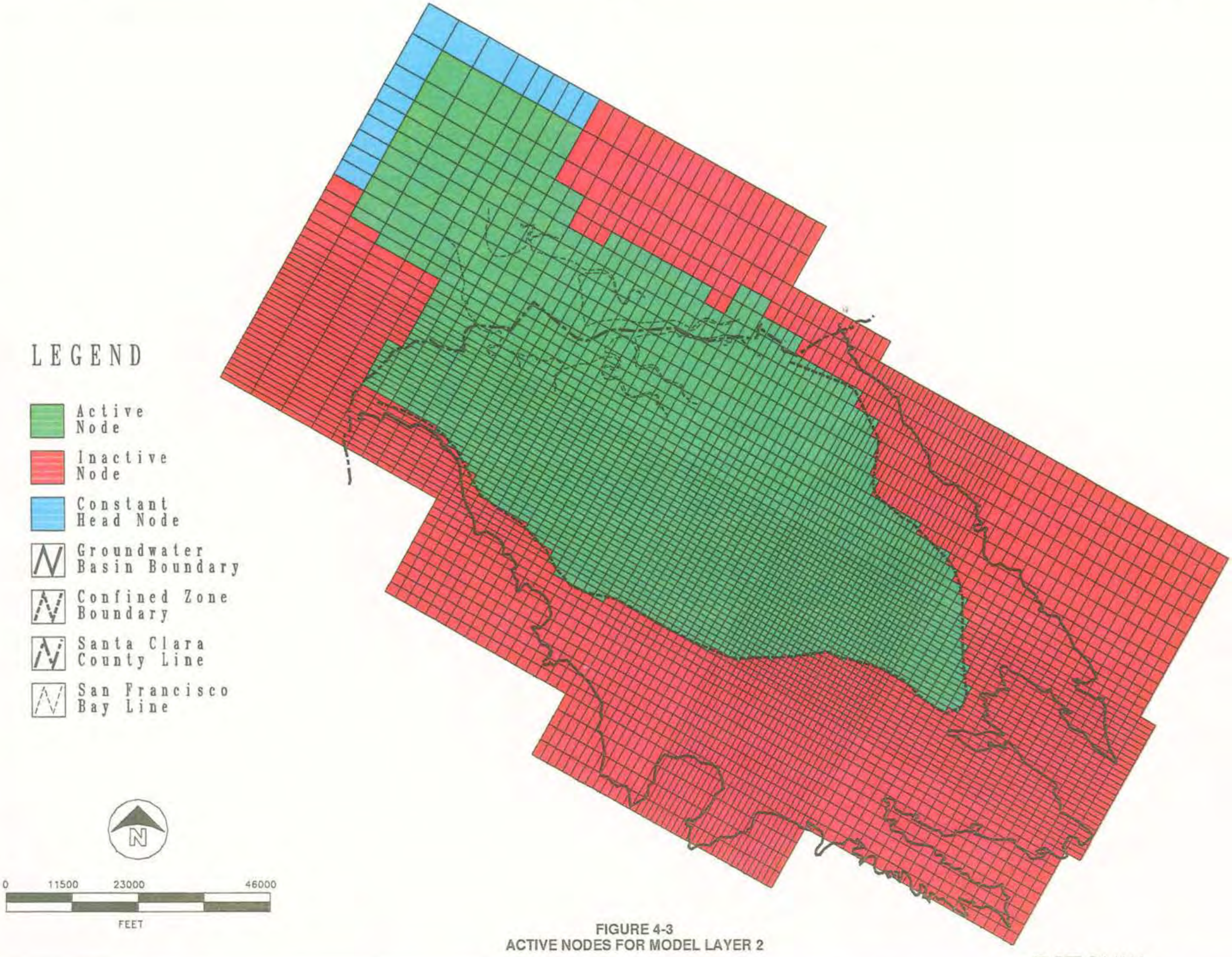


FIGURE 4-3
ACTIVE NODES FOR MODEL LAYER 2

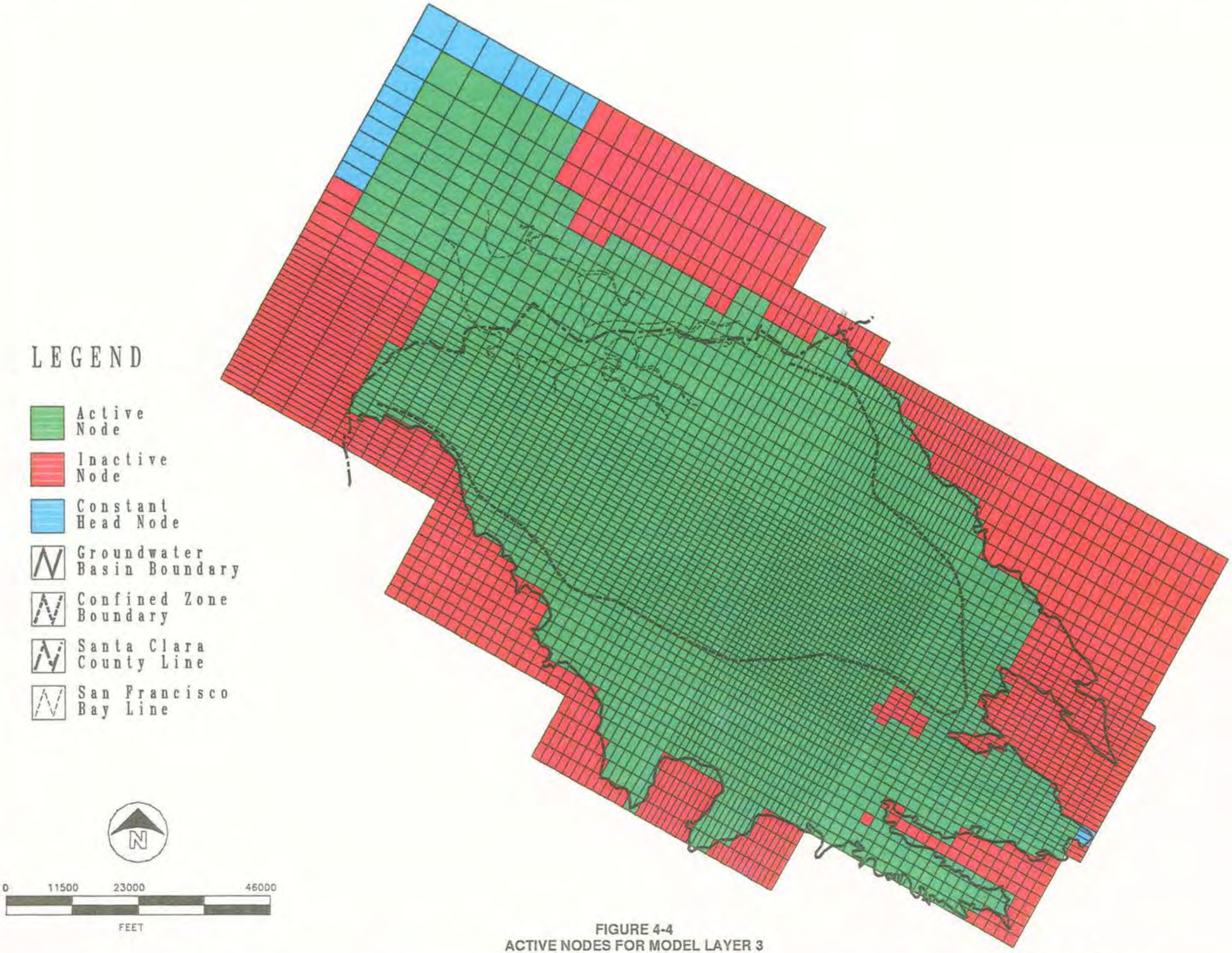


FIGURE 4-4
ACTIVE NODES FOR MODEL LAYER 3

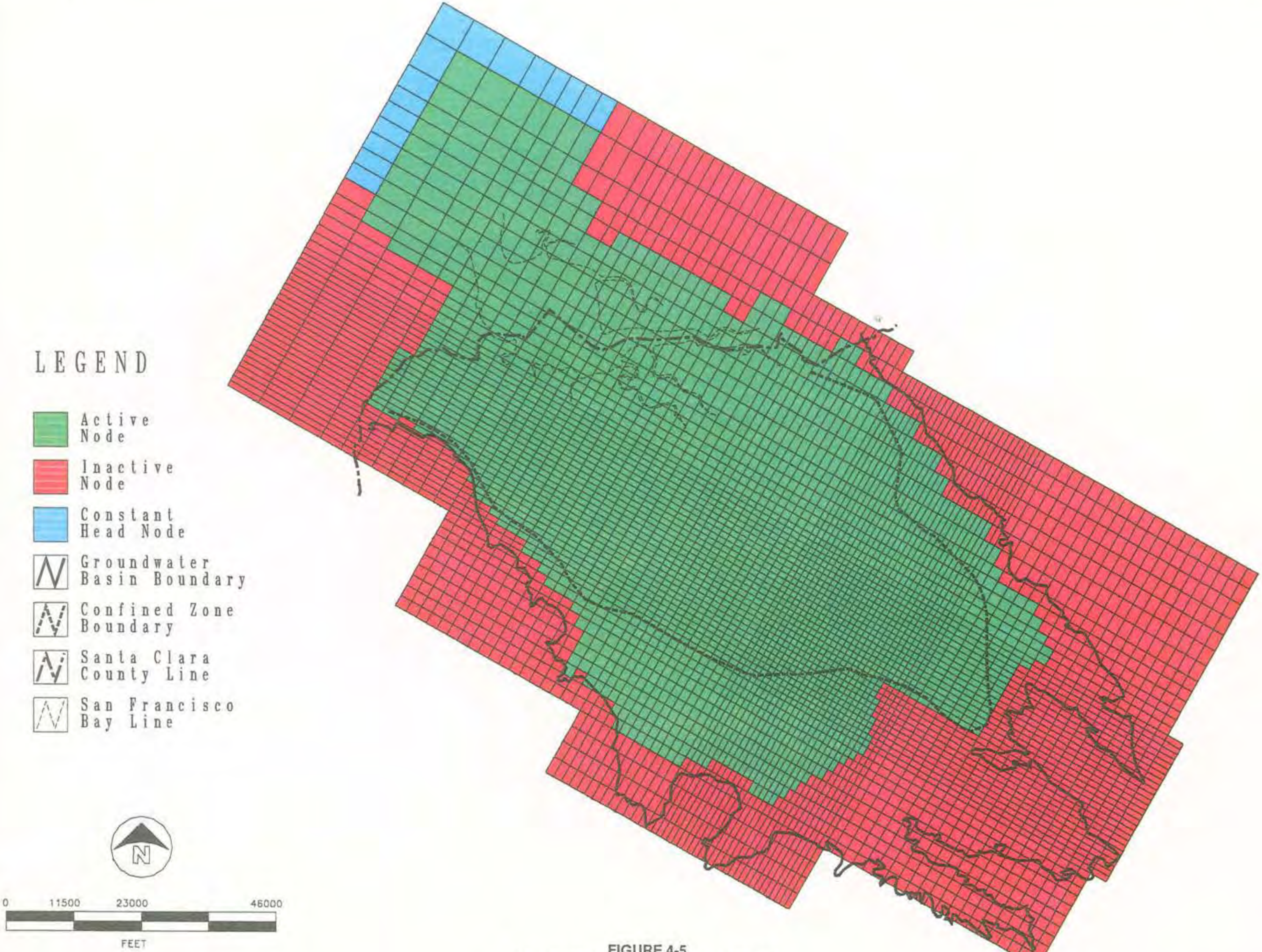


FIGURE 4-5
ACTIVE NODES FOR MODEL LAYER 4

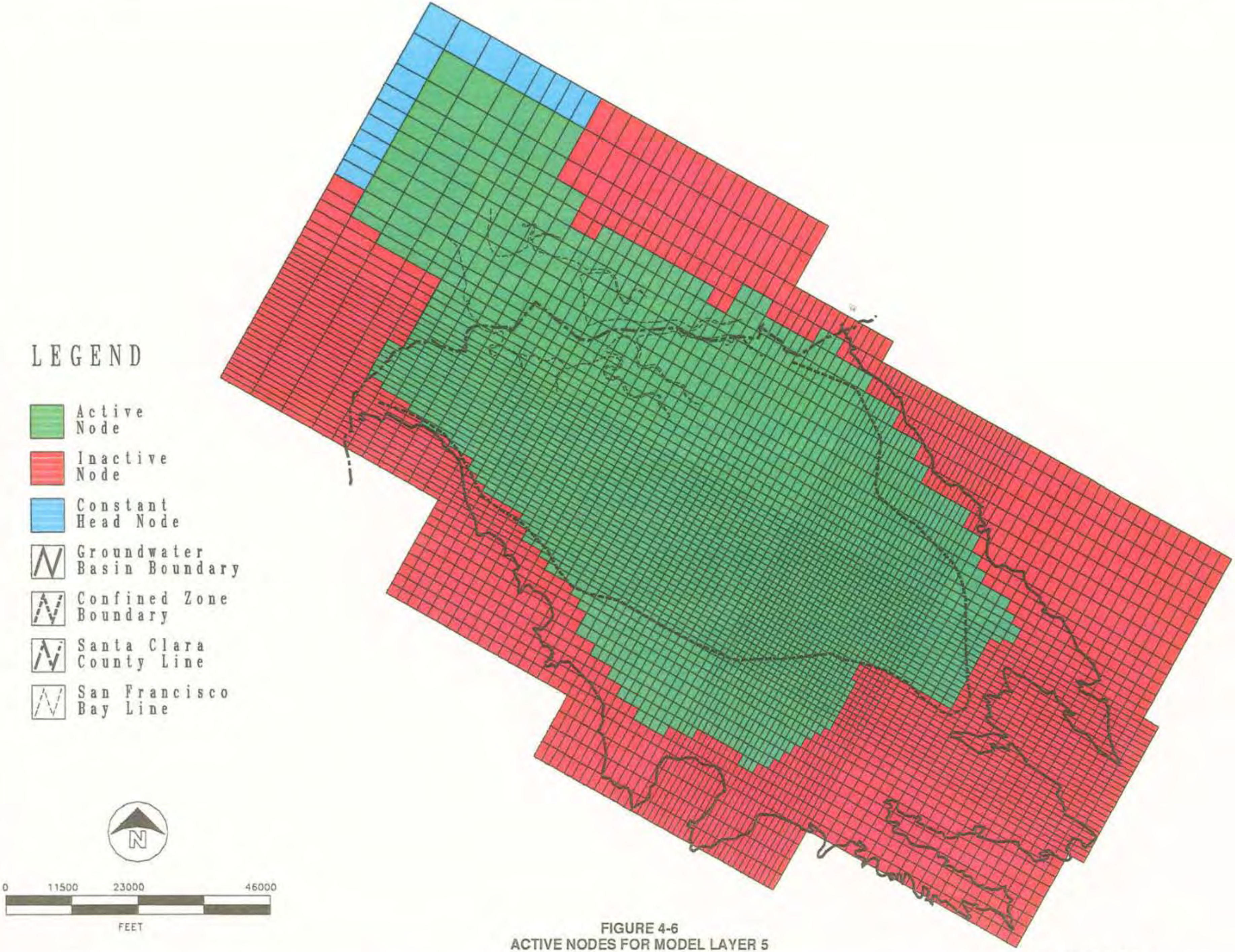


FIGURE 4-6
ACTIVE NODES FOR MODEL LAYER 5

CH2M HILL

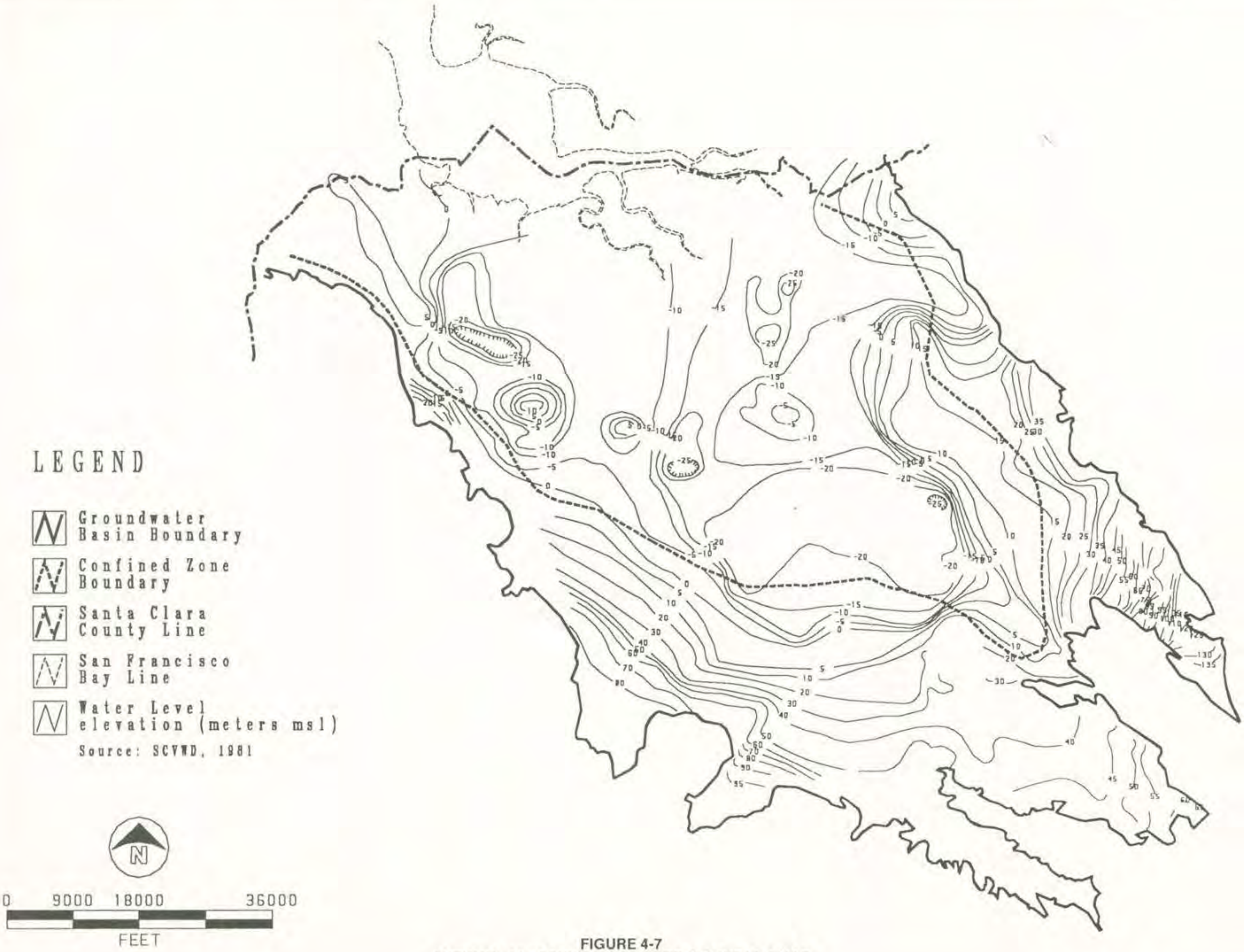
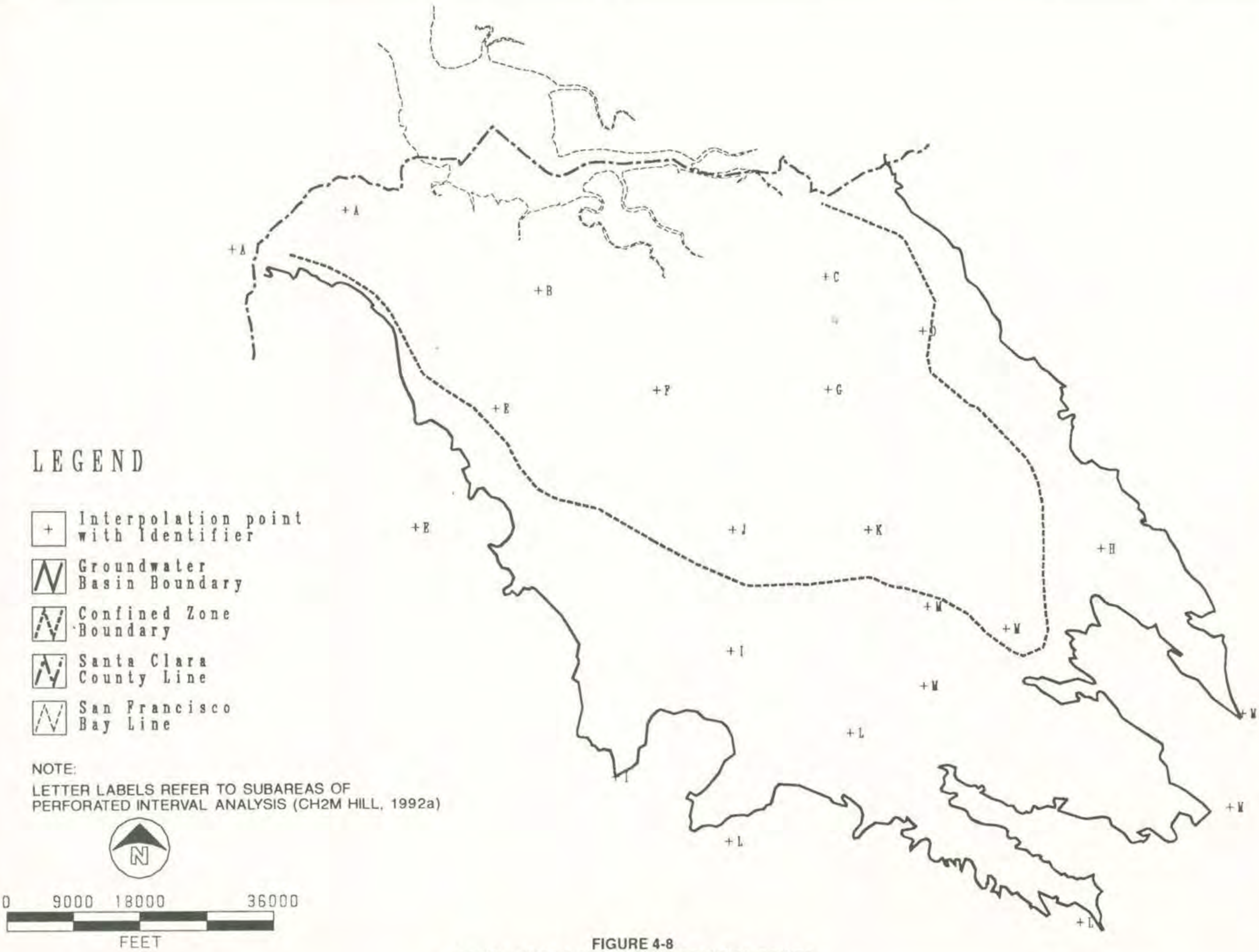


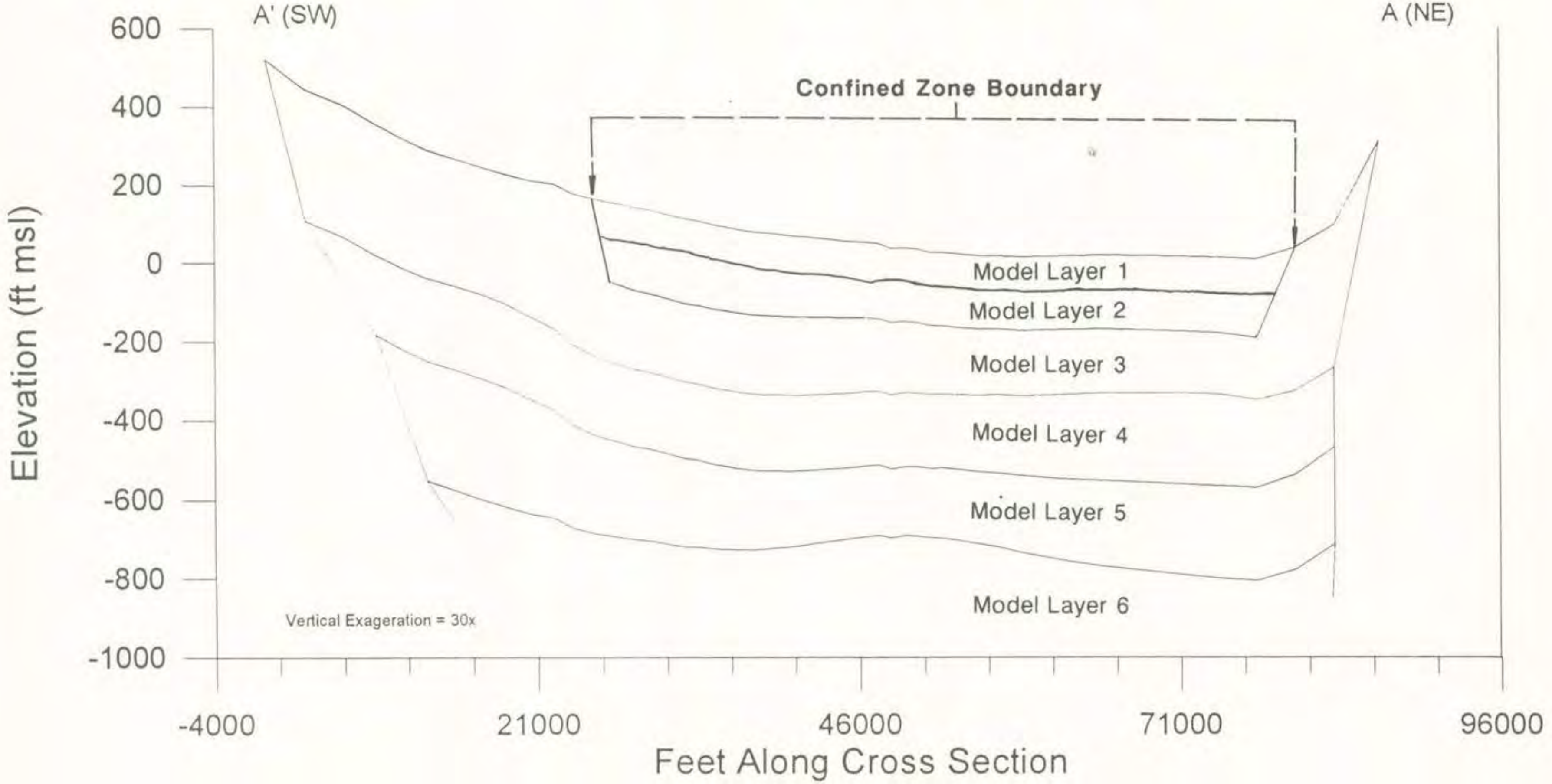
FIGURE 4-7
AUTUMN 1981 SCVWD PIEZOMETRIC SURFACE MAP



NOTE:

LETTER LABELS REFER TO SUBAREAS OF PERFORATED INTERVAL ANALYSIS (CH2M HILL, 1992a)

FIGURE 4-8
MODEL LAYER BOTTOM INTERPOLATION POINTS



NOTE:
SEE FIGURE 4-10 FOR CROSS SECTION LOCATION

FIGURE 4-9
CROSS SECTION A-A'
OF INITIAL NUMERICAL MODEL LAYERING

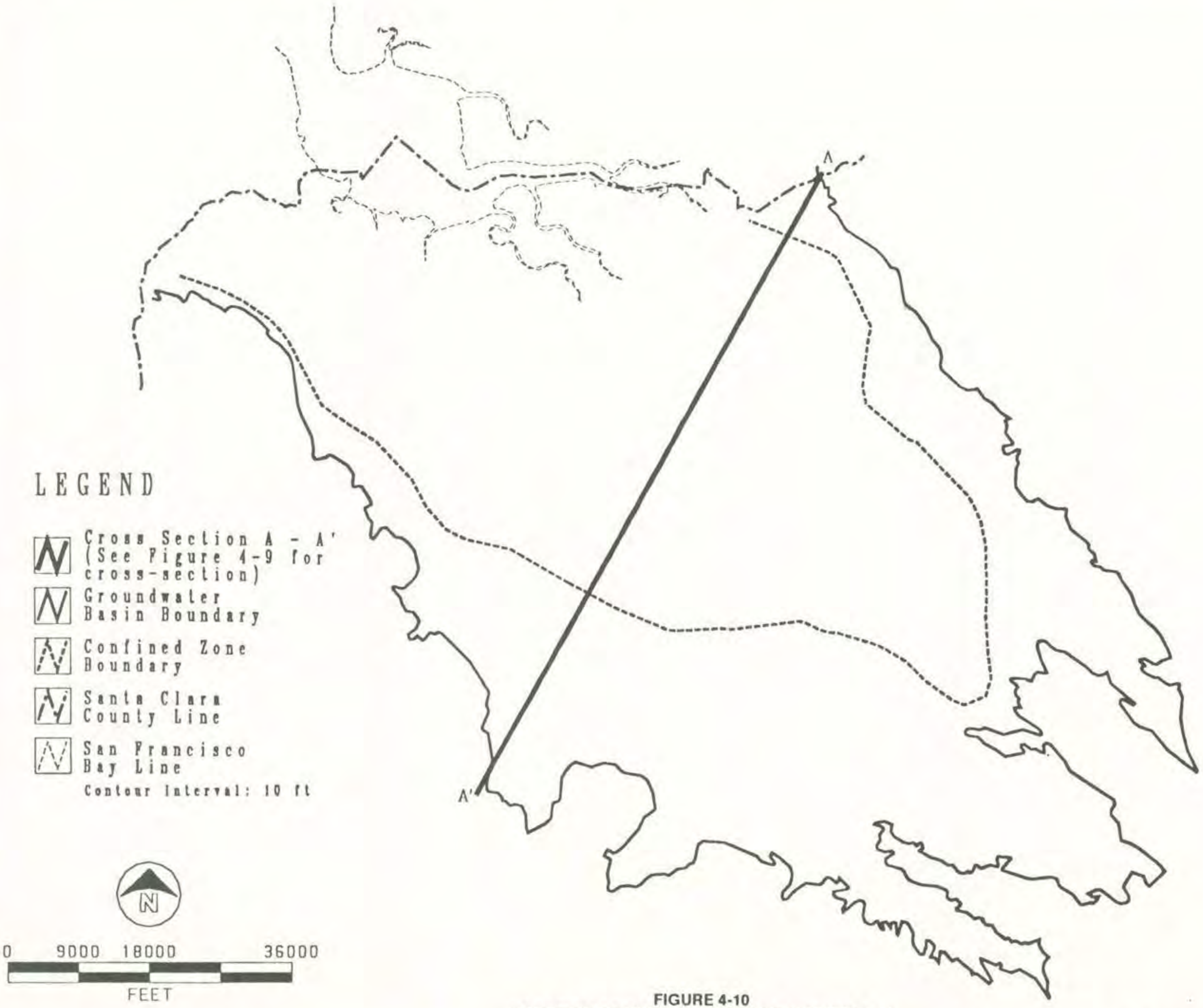


FIGURE 4-10
LOCATION OF SCHEMATIC CROSS-SECTION A-A'

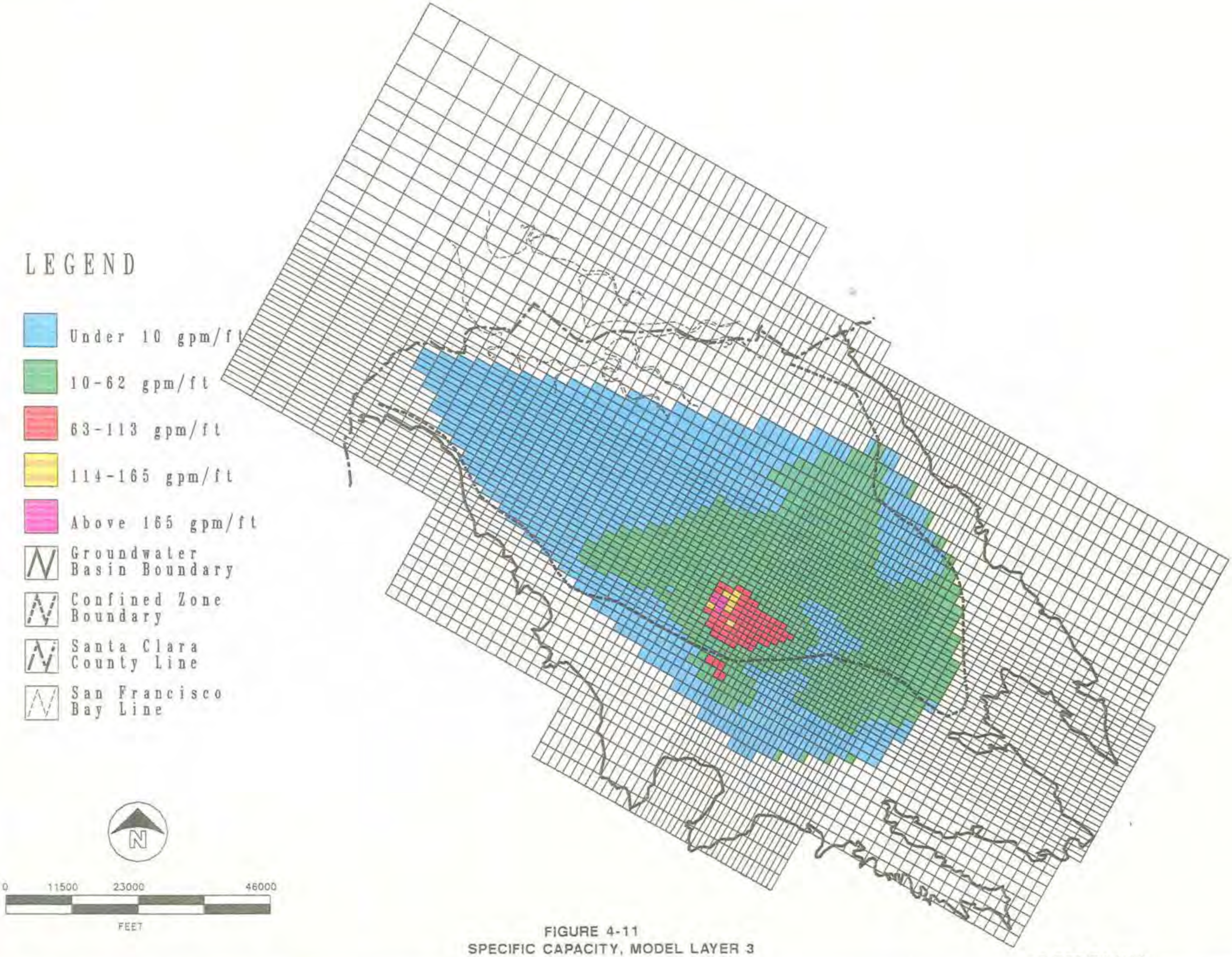


FIGURE 4-11
SPECIFIC CAPACITY, MODEL LAYER 3

CH2M HILL

SPC3.AML SFO27295.BM

October 18, 1992

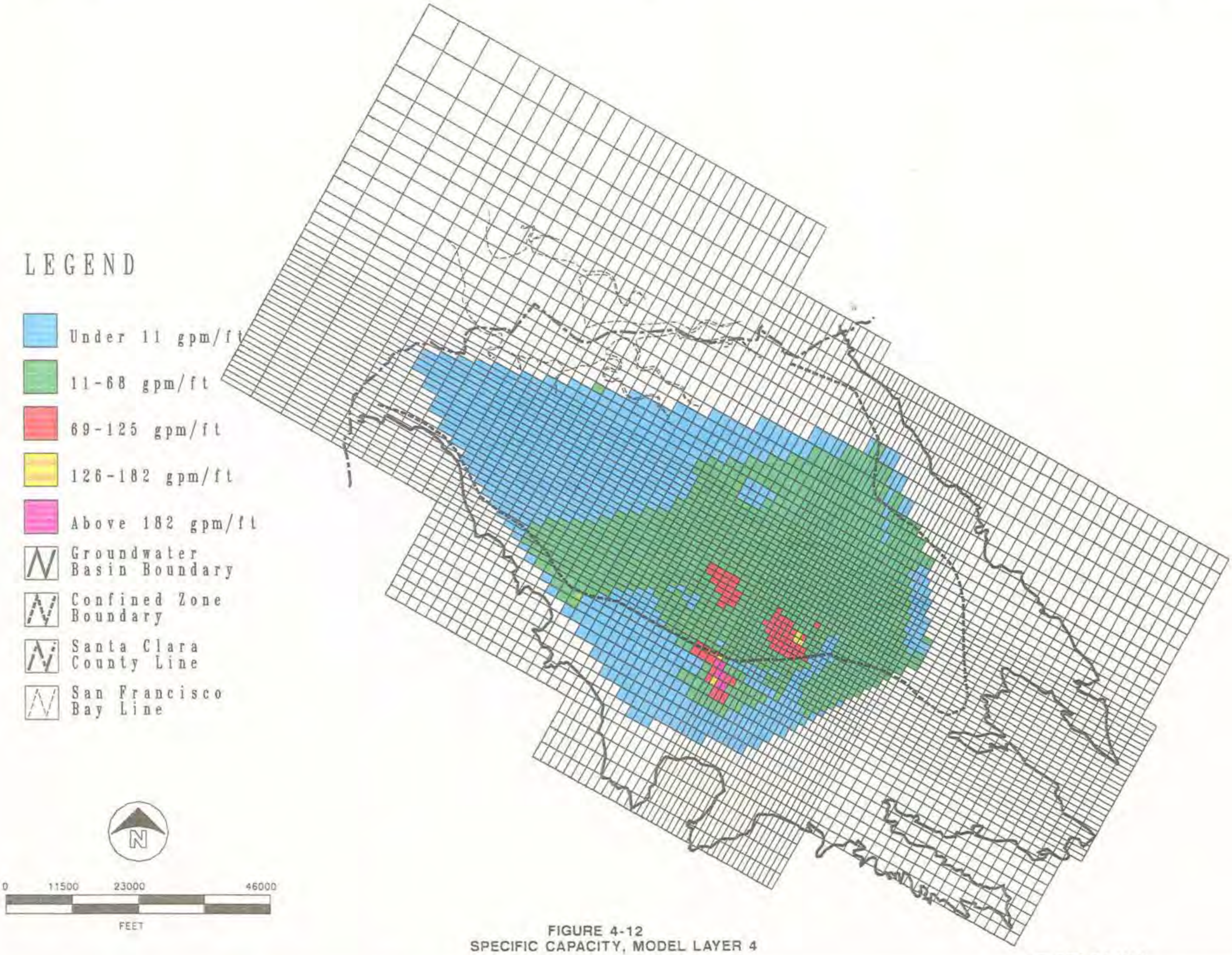


FIGURE 4-12
SPECIFIC CAPACITY, MODEL LAYER 4

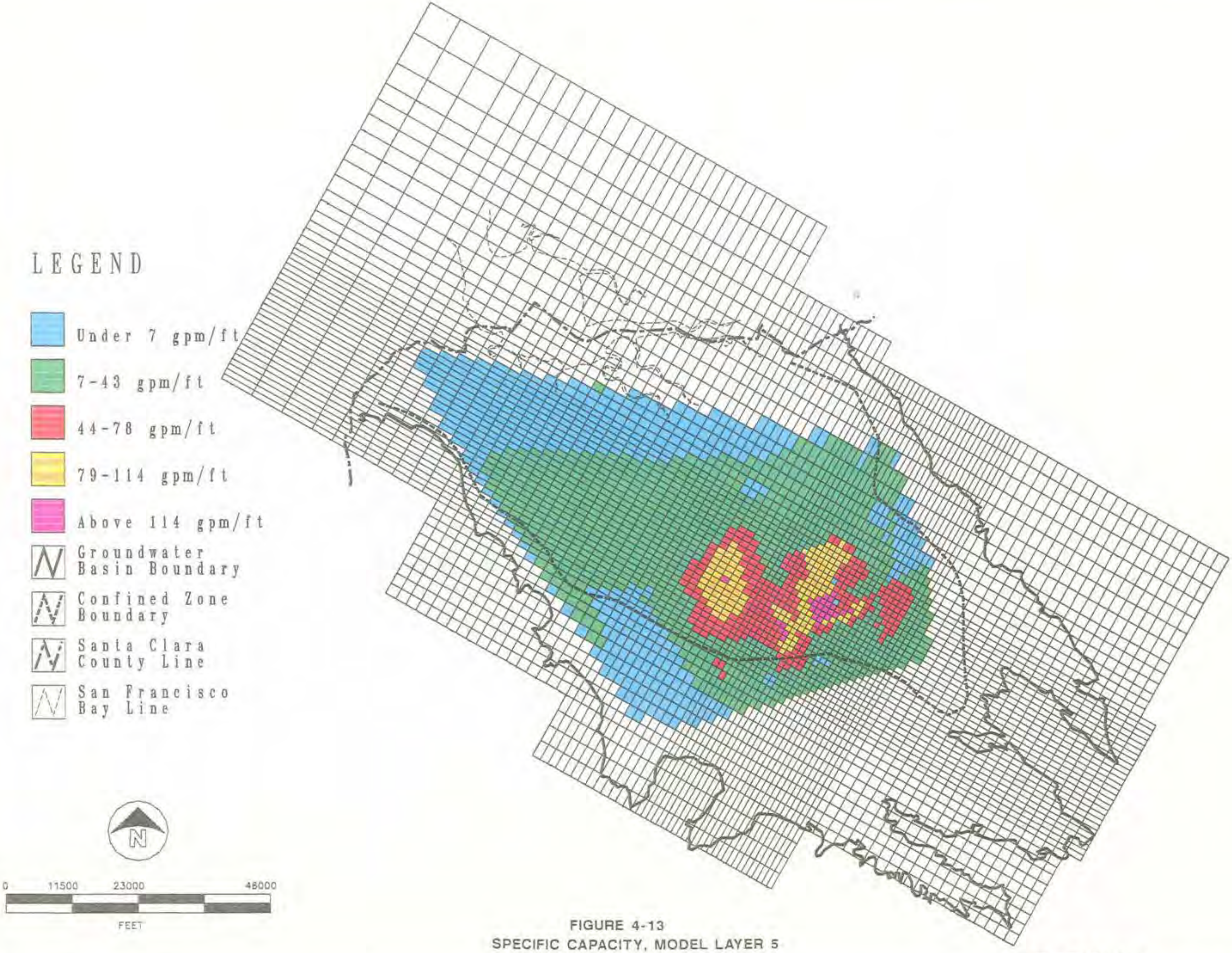


FIGURE 4-13
SPECIFIC CAPACITY, MODEL LAYER 5

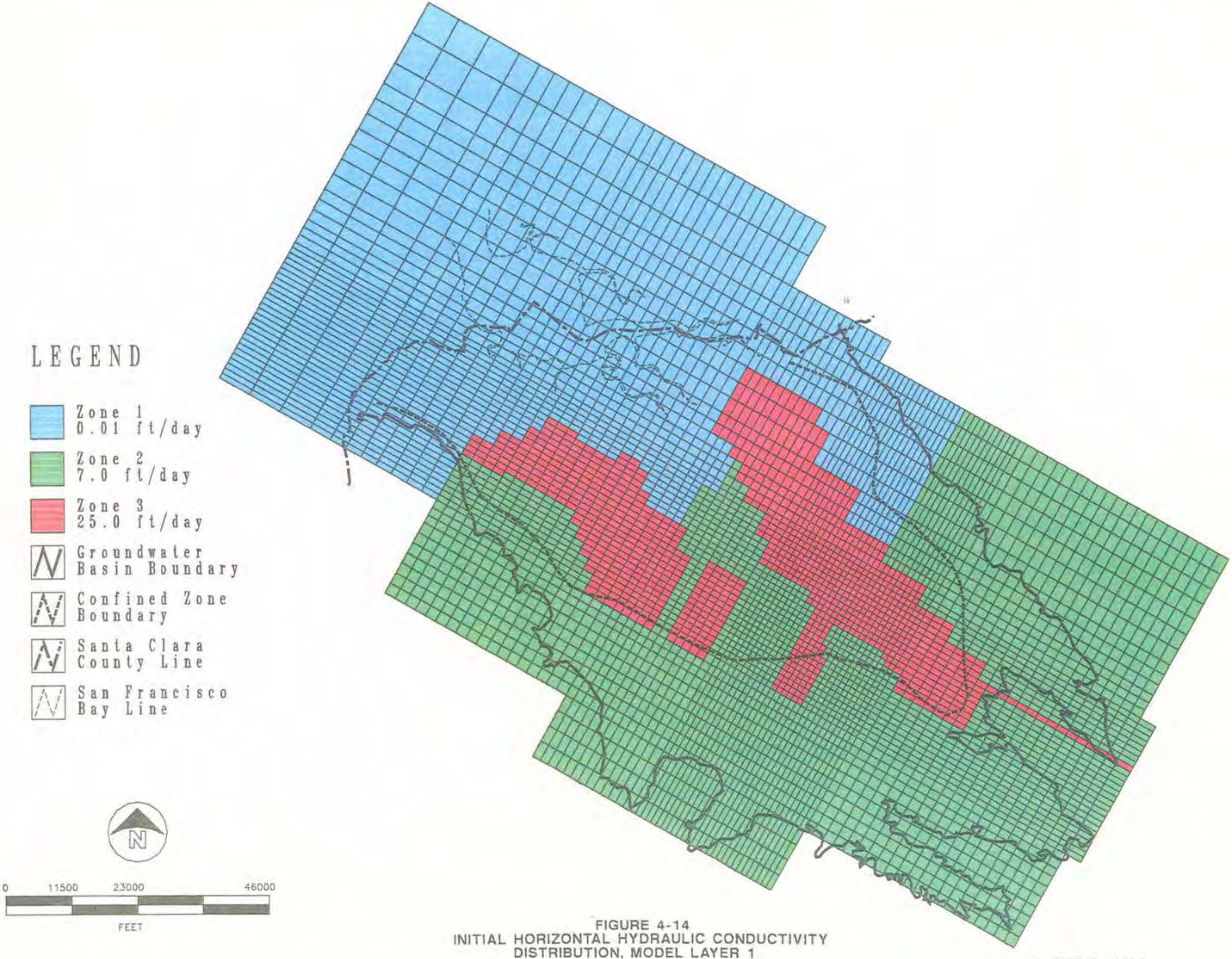


FIGURE 4-14
INITIAL HORIZONTAL HYDRAULIC CONDUCTIVITY
DISTRIBUTION, MODEL LAYER 1

CH2M HILL

October 12, 1992

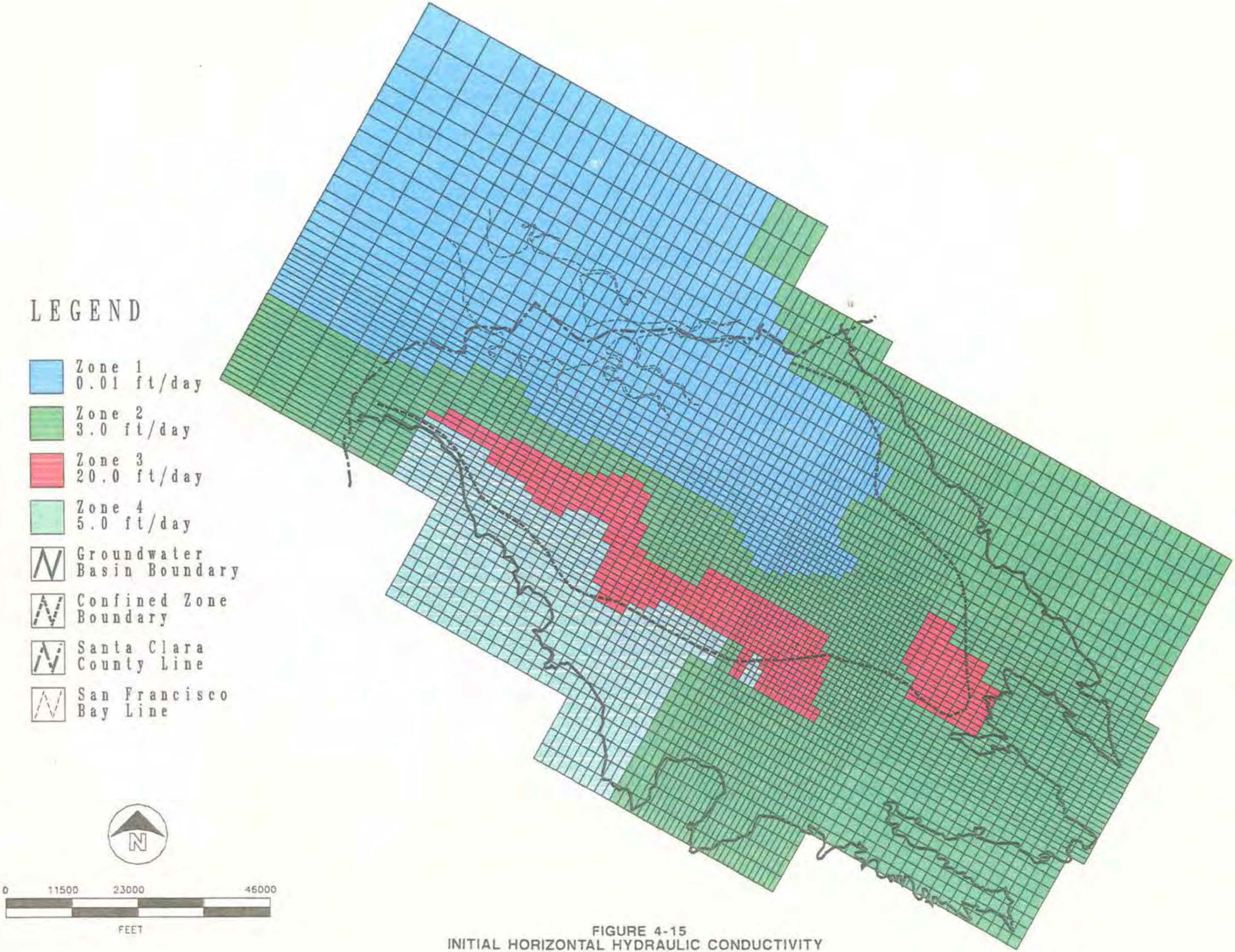


FIGURE 4-15
INITIAL HORIZONTAL HYDRAULIC CONDUCTIVITY
DISTRIBUTION, MODEL LAYER 2

SFO27295.BM

October 13, 1992

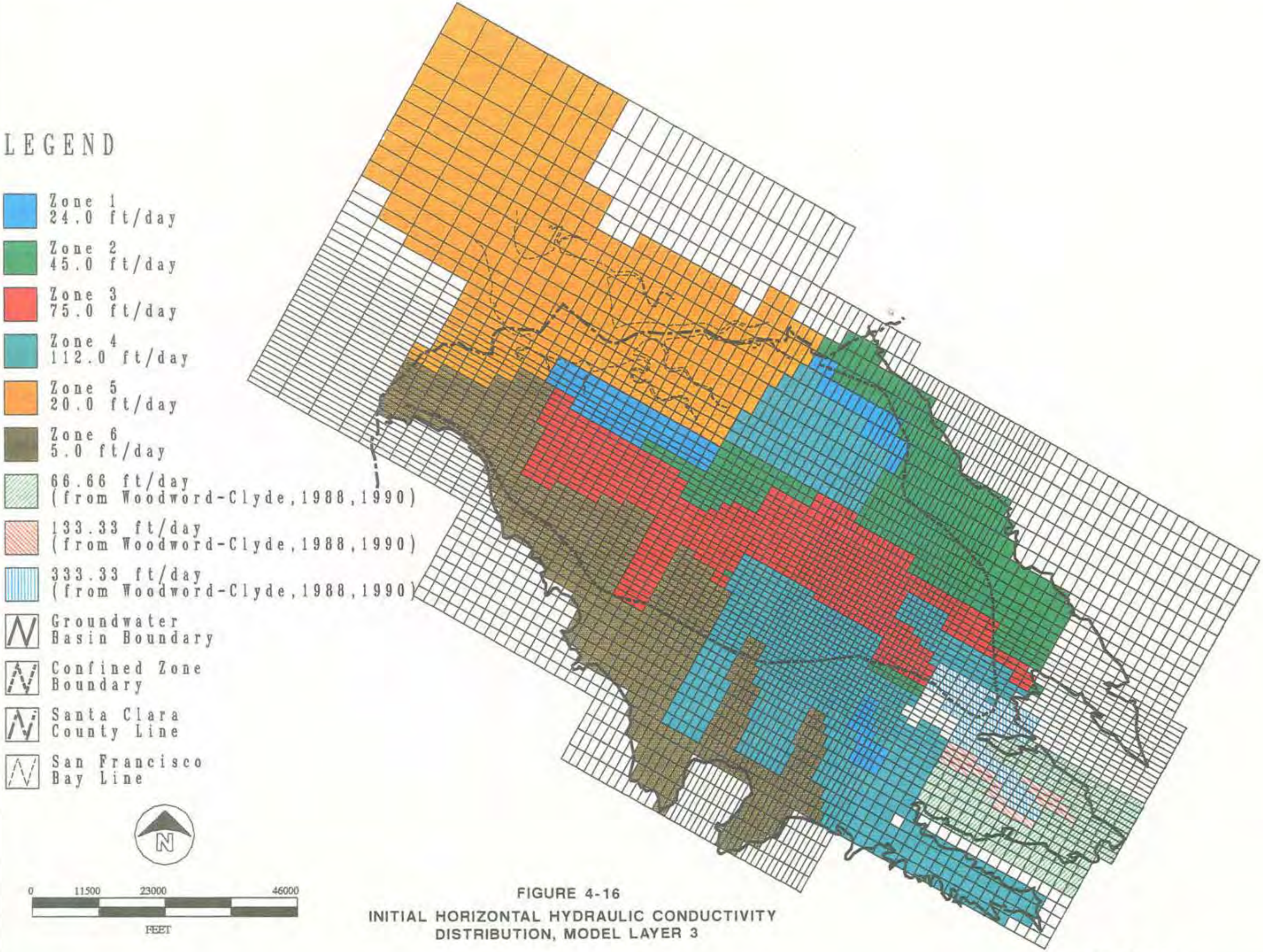


FIGURE 4-16
INITIAL HORIZONTAL HYDRAULIC CONDUCTIVITY
DISTRIBUTION, MODEL LAYER 3

E3.AML

December 09, 1992

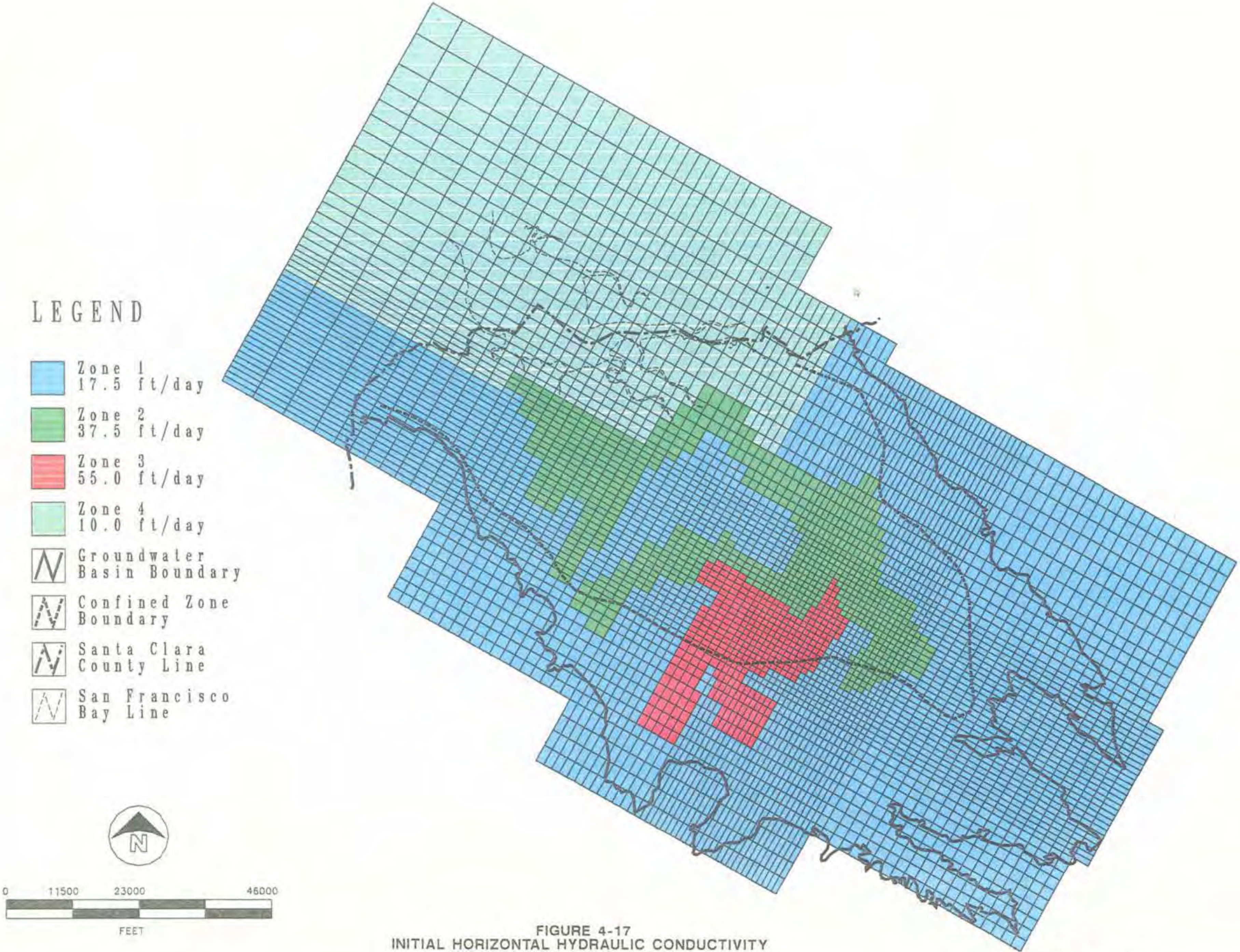


FIGURE 4-17
INITIAL HORIZONTAL HYDRAULIC CONDUCTIVITY
DISTRIBUTION, MODEL LAYER 4

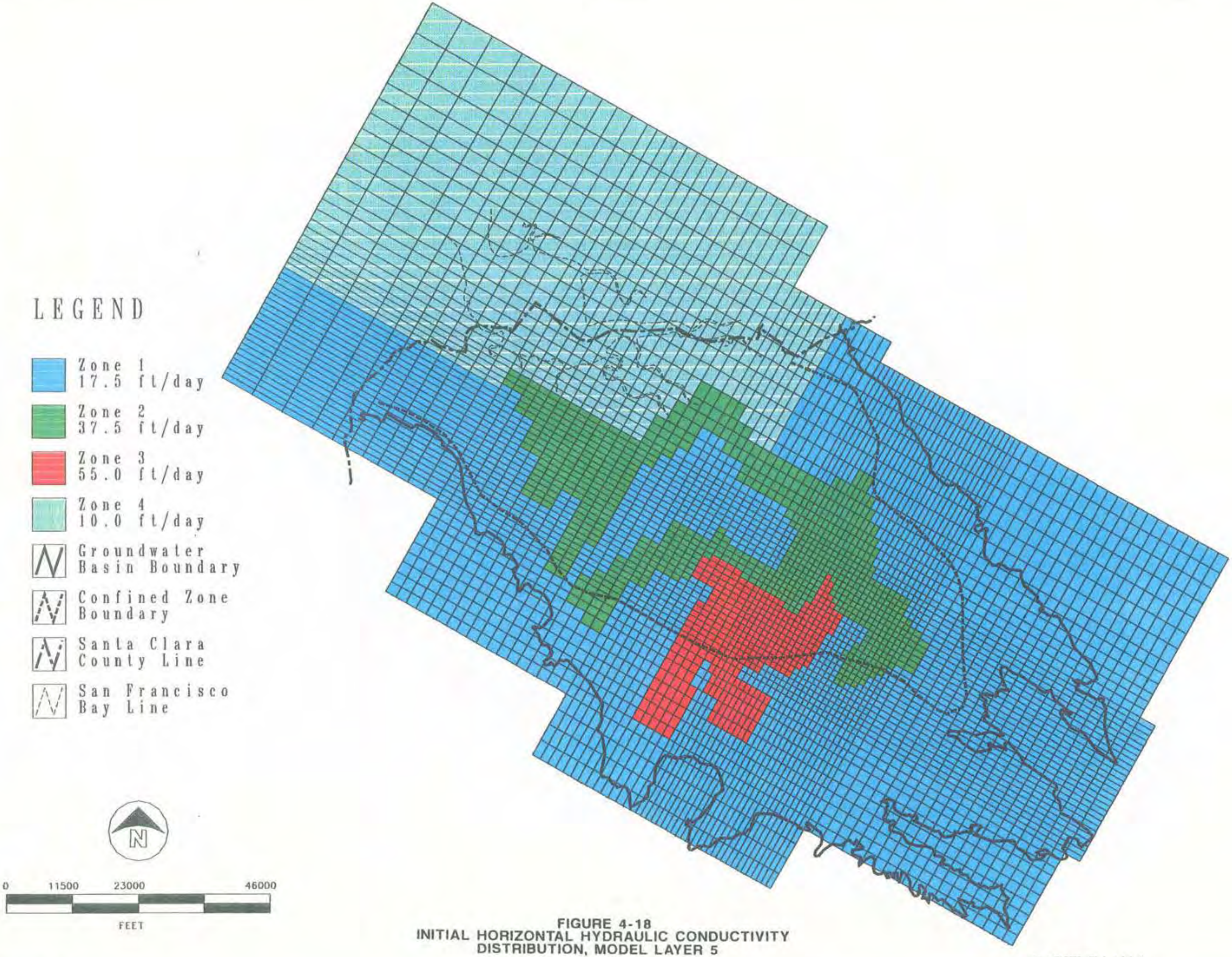
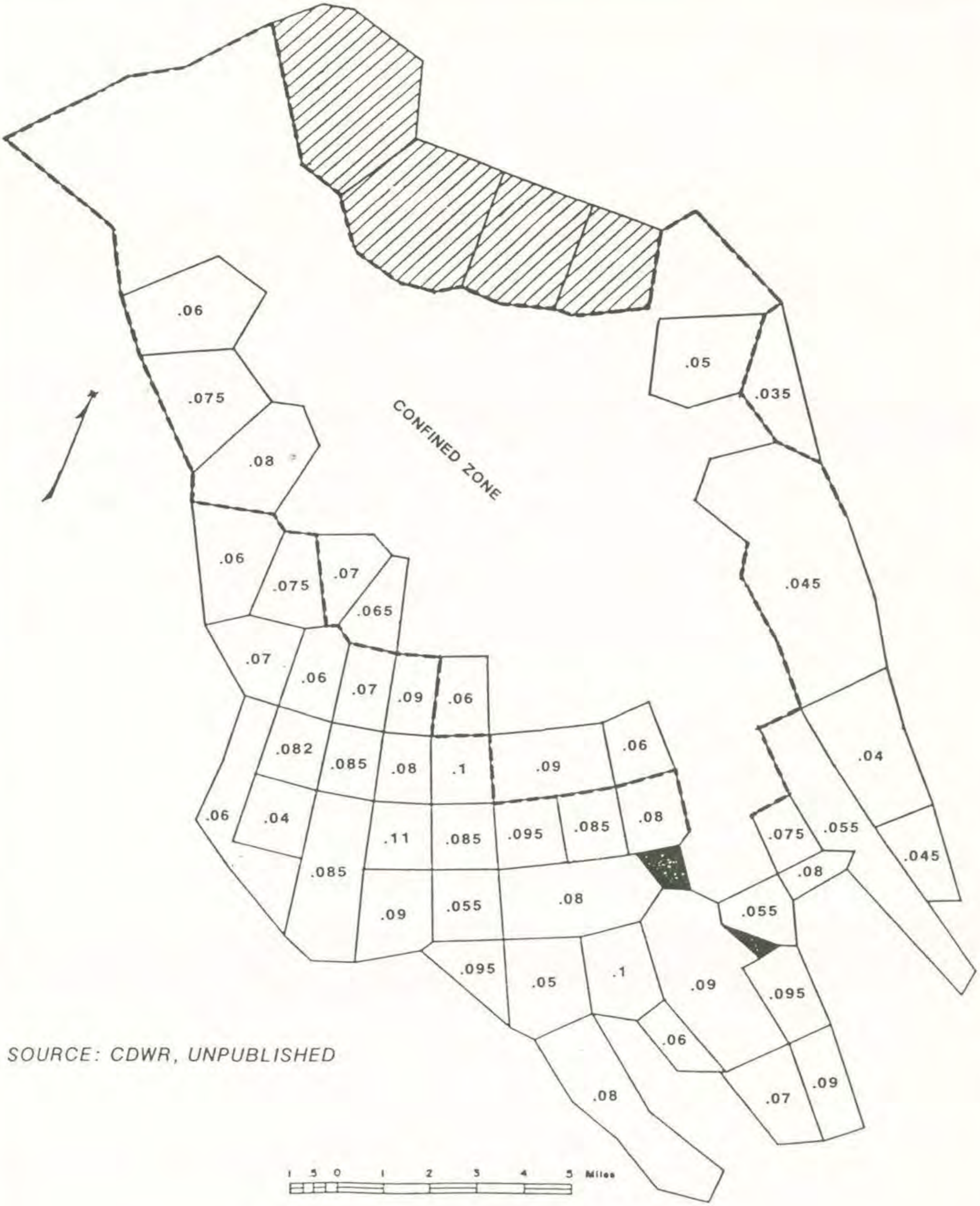


FIGURE 4-18
INITIAL HORIZONTAL HYDRAULIC CONDUCTIVITY DISTRIBUTION, MODEL LAYER 5

CH2M HILL

October 12, 1992



SOURCE: CDWR, UNPUBLISHED

FIGURE 4-19
ESTIMATED SPECIFIC YIELD

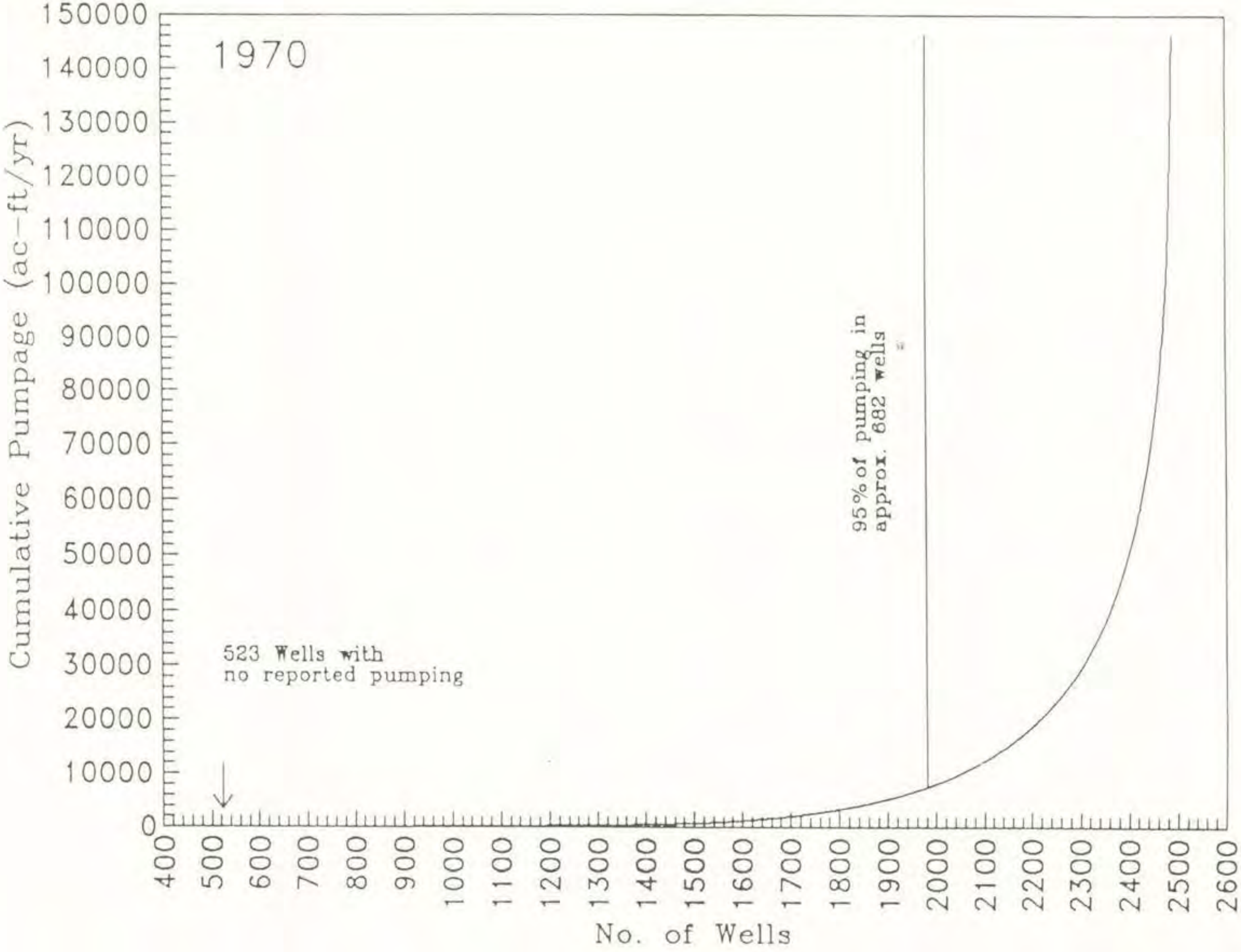


FIGURE 4-20
SAMPLE CUMULATIVE PUMPING GRAPH

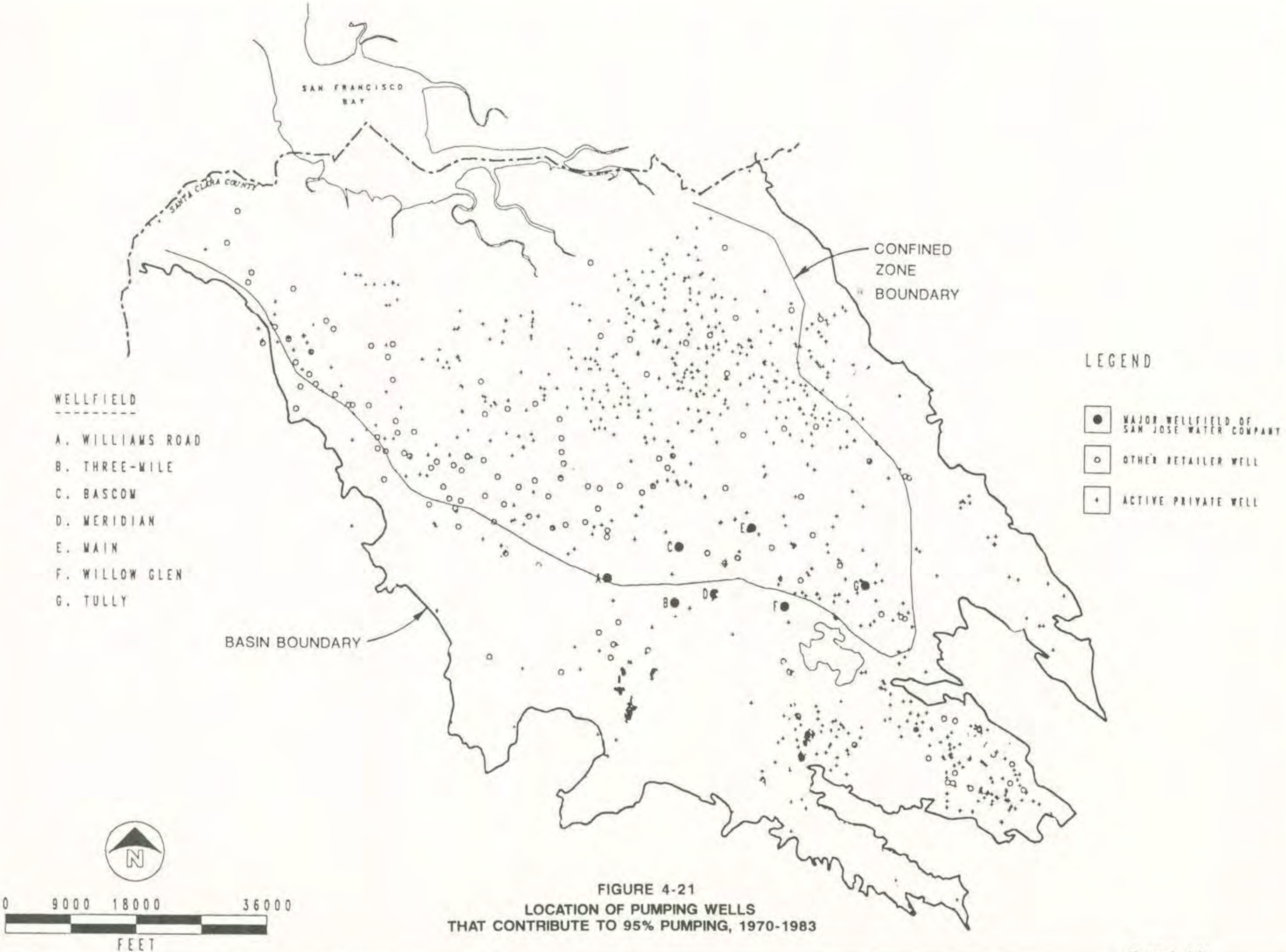


FIGURE 4-21
LOCATION OF PUMPING WELLS
THAT CONTRIBUTE TO 95% PUMPING, 1970-1983

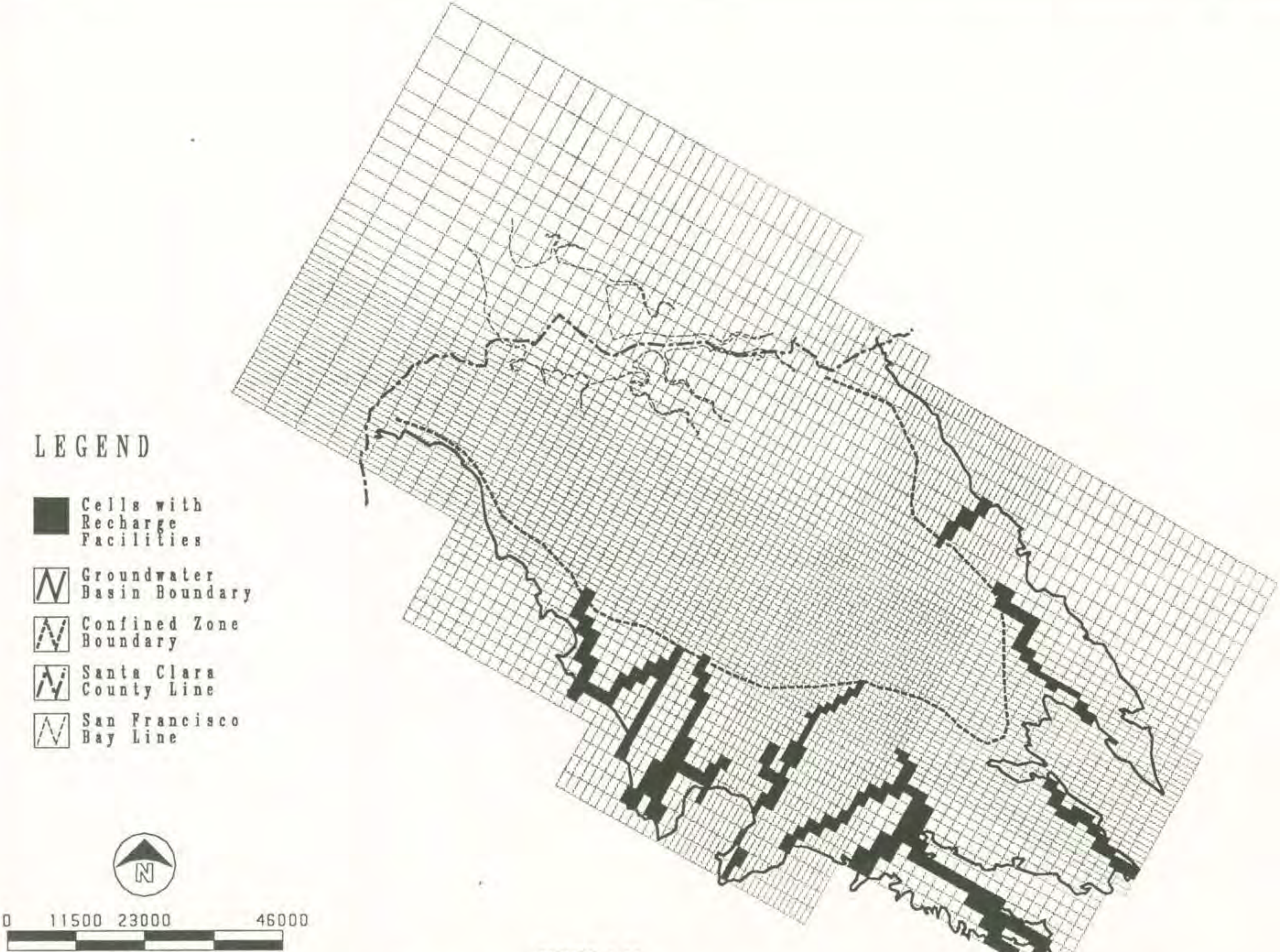


FIGURE 4-22
CELLS WHICH SIMULATE EVAPOTRANSPIRATION

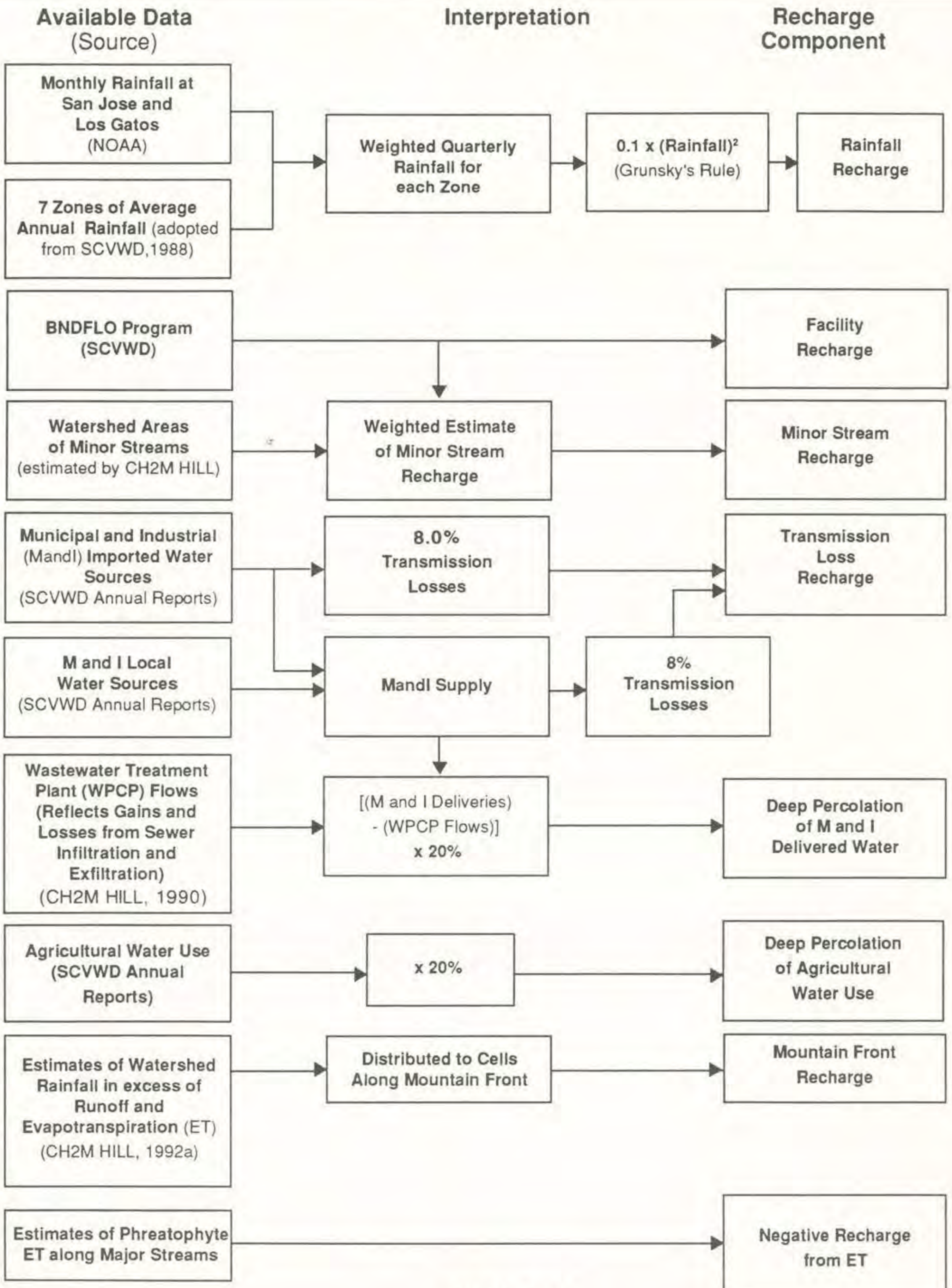

Available Data (Source)
Interpretation
Recharge Component
Monthly Rainfall at San Jose and Los Gatos (NOAA)
7 Zones of Average Annual Rainfall (adopted from SCVWD,1988)
Weighted Quarterly Rainfall for each Zone
0.1 x (Rainfall)²
(Grunsky's Rule)
Rainfall Recharge
BNDFLO Program (SCVWD)
Facility Recharge
Watershed Areas of Minor Streams (estimated by CH2M HILL)
Weighted Estimate of Minor Stream Recharge
Minor Stream Recharge
Municipal and Industrial (MandI) Imported Water Sources (SCVWD Annual Reports)
8.0% Transmission Losses
Transmission Loss Recharge
M and I Local Water Sources (SCVWD Annual Reports)
MandI Supply
8% Transmission Losses
Wastewater Treatment Plant (WPCP) Flows (Reflects Gains and Losses from Sewer Infiltration and Exfiltration) (CH2M HILL, 1990)
[(M and I Deliveries) - (WPCP Flows)] x 20%
Deep Percolation of M and I Delivered Water
Agricultural Water Use (SCVWD Annual Reports)
x 20%
Deep Percolation of Agricultural Water Use
Estimates of Watershed Rainfall in excess of Runoff and Evapotranspiration (ET) (CH2M HILL, 1992a)
Distributed to Cells Along Mountain Front
Mountain Front Recharge
Estimates of Phreatophyte ET along Major Streams
Negative Recharge from ET

FIGURE 4-23
FLOWCHART FOR CONSTRUCTING AREAL RECHARGE MATRIX
FOR NUMERICAL MODEL

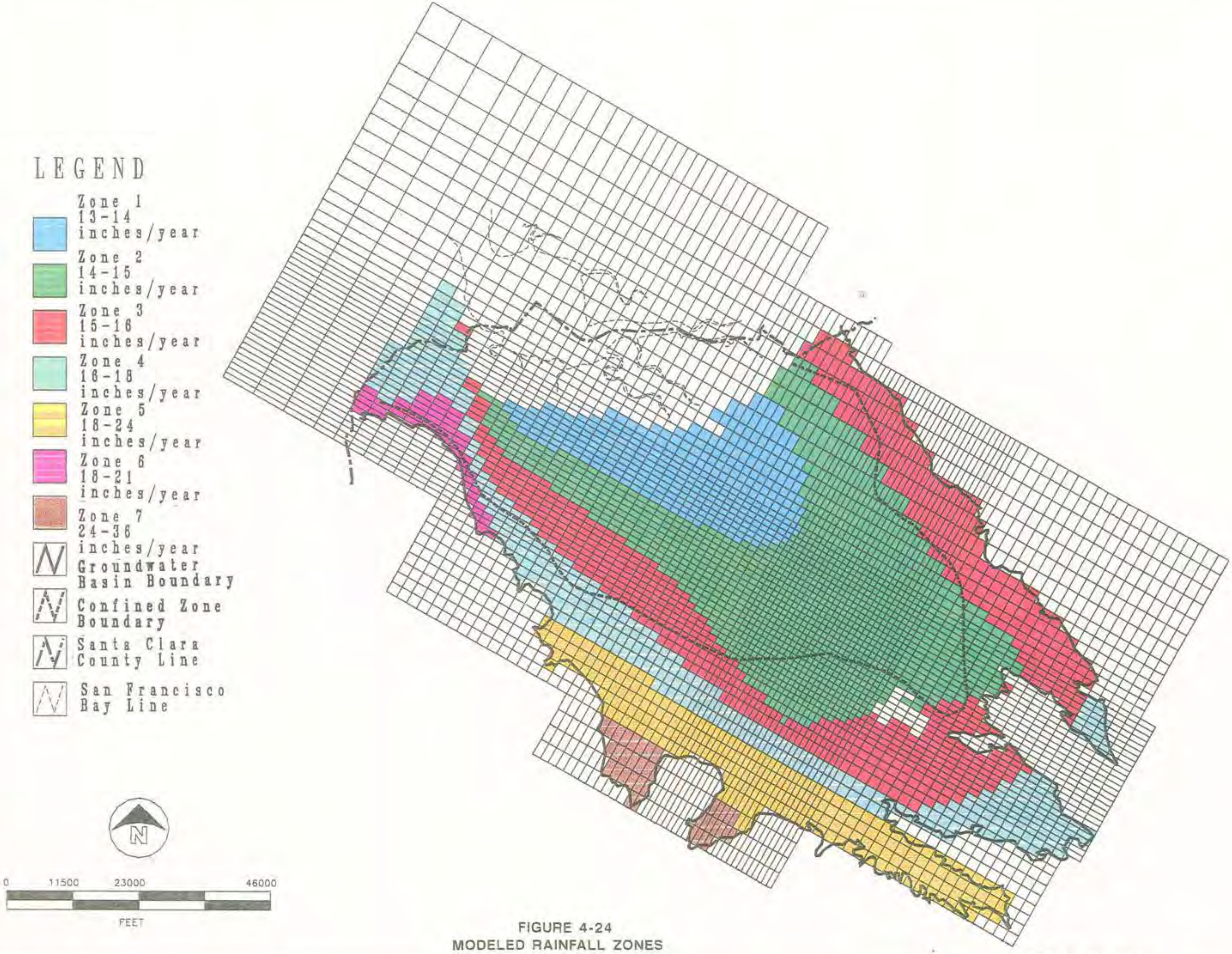


FIGURE 4-24
MODELED RAINFALL ZONES

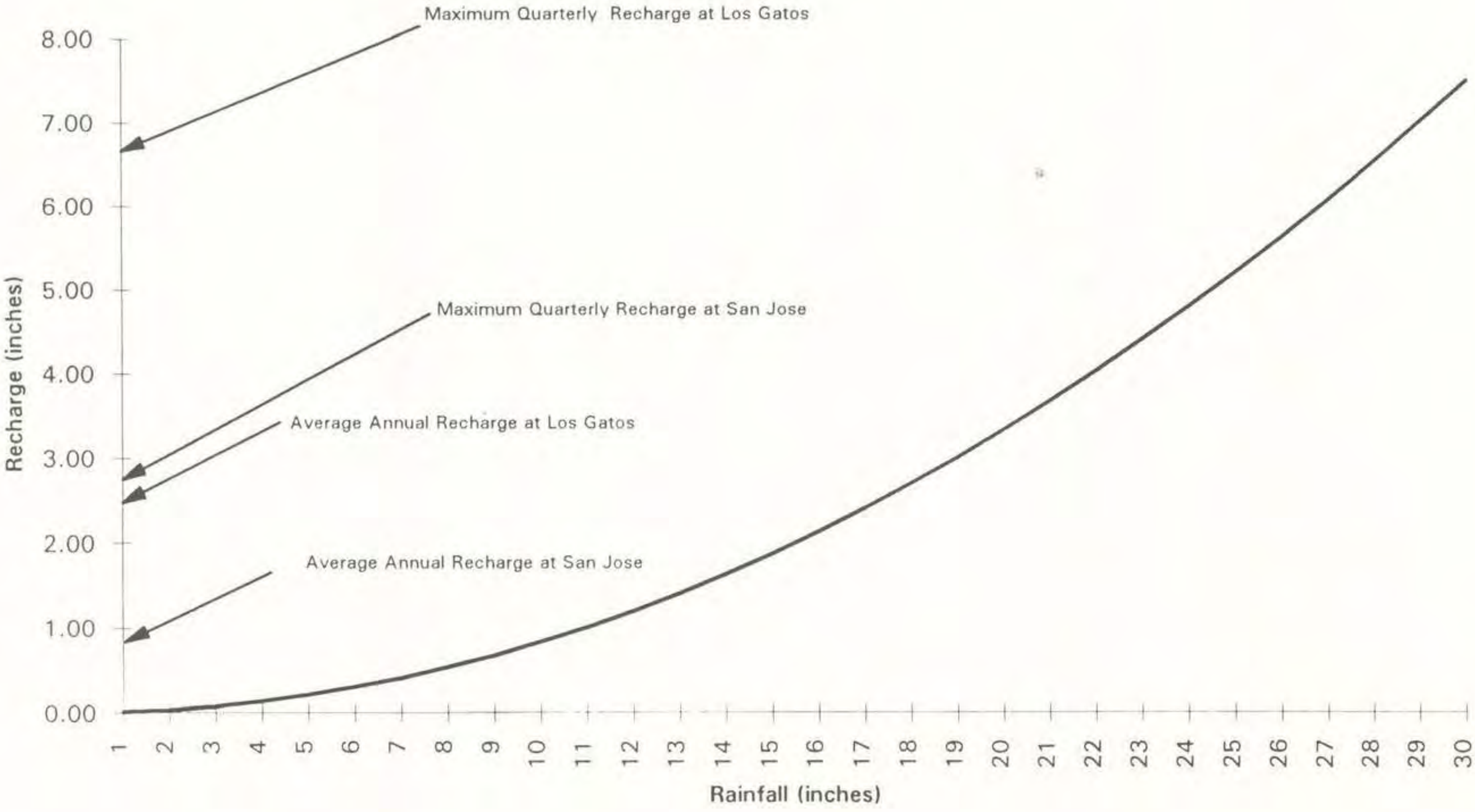


FIGURE 4-25
RAINFALL RECHARGE RELATIONSHIP

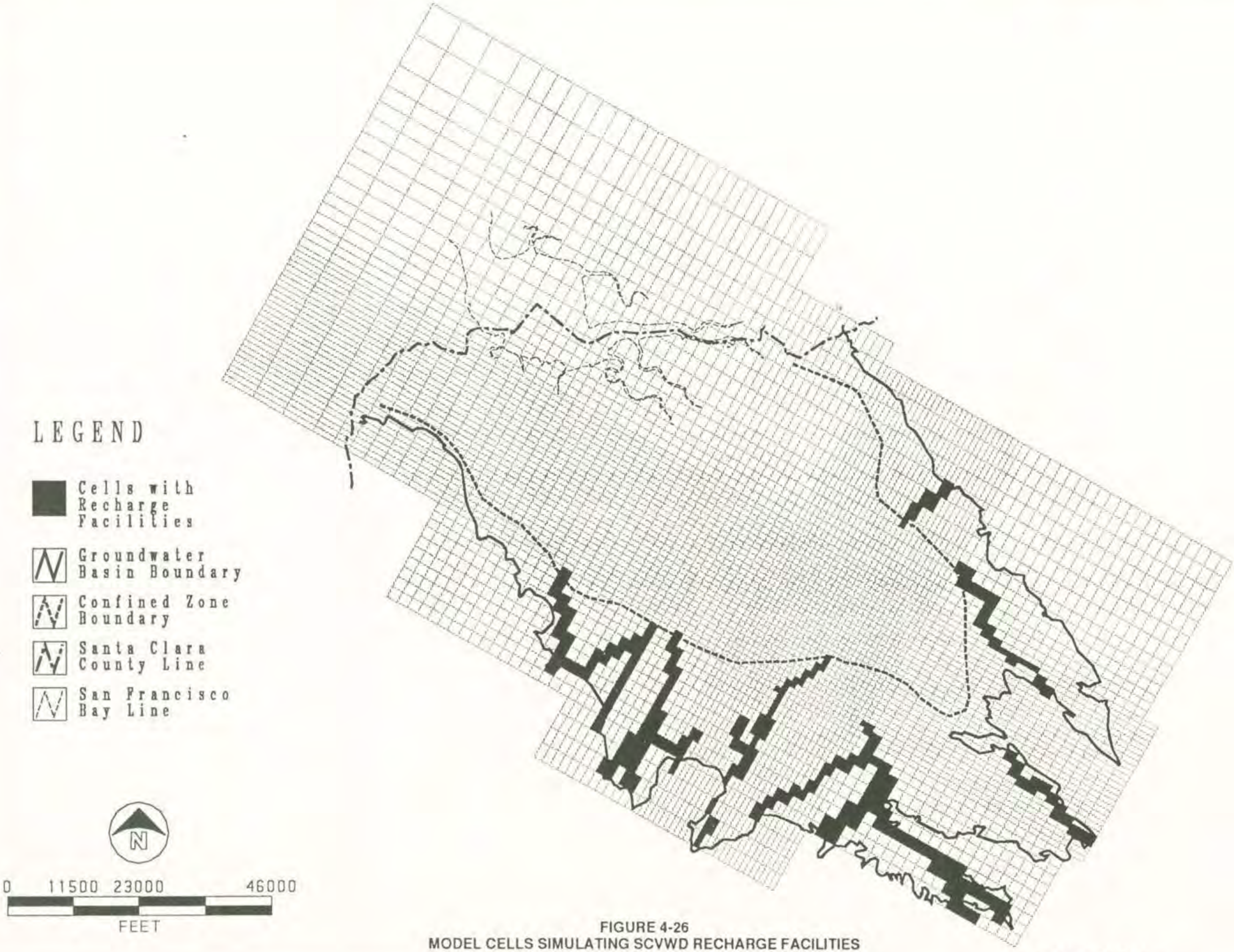


FIGURE 4-26
MODEL CELLS SIMULATING SCVWD RECHARGE FACILITIES

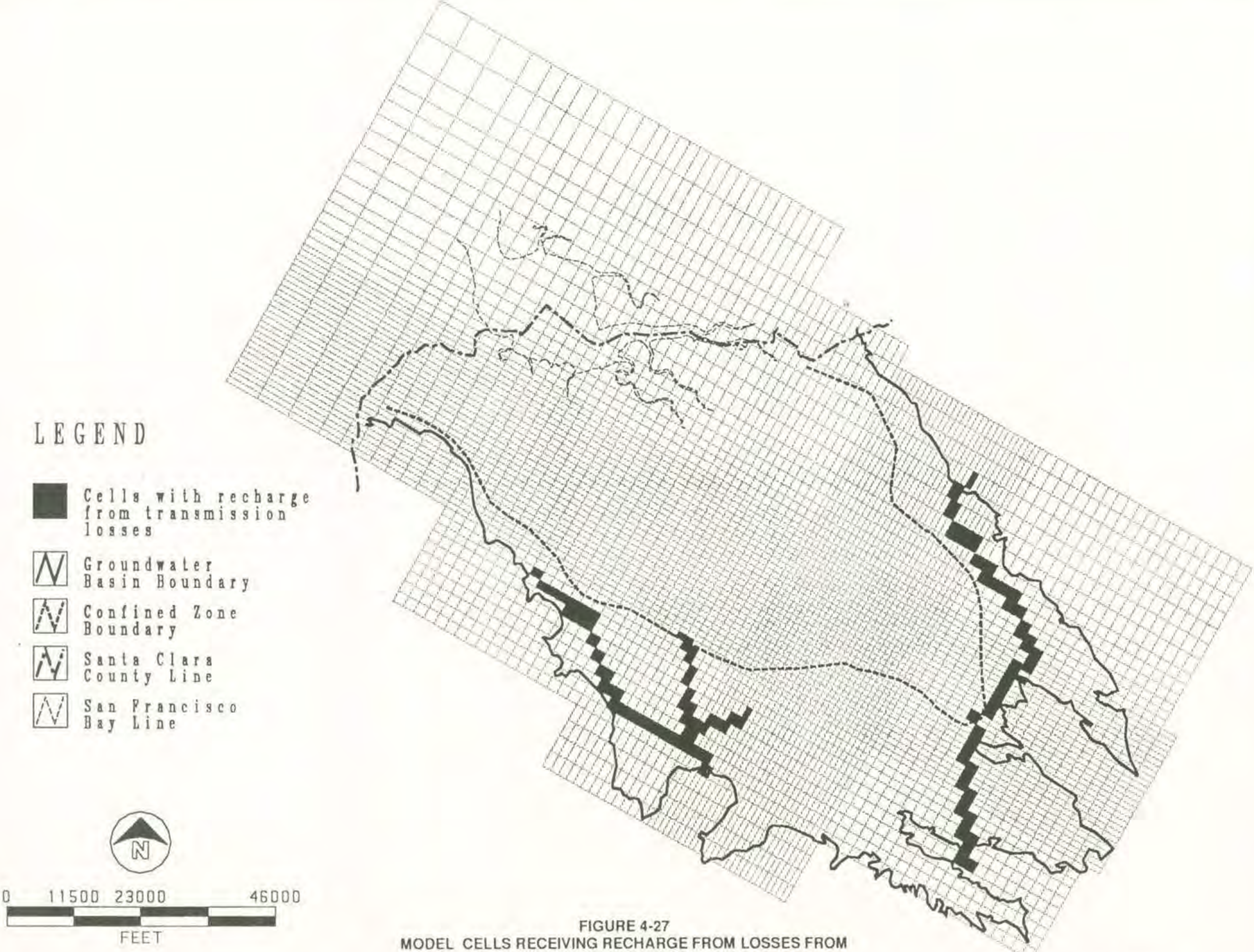


FIGURE 4-27
MODEL CELLS RECEIVING RECHARGE FROM LOSSES FROM SCVWD'S TRANSMISSION LINES

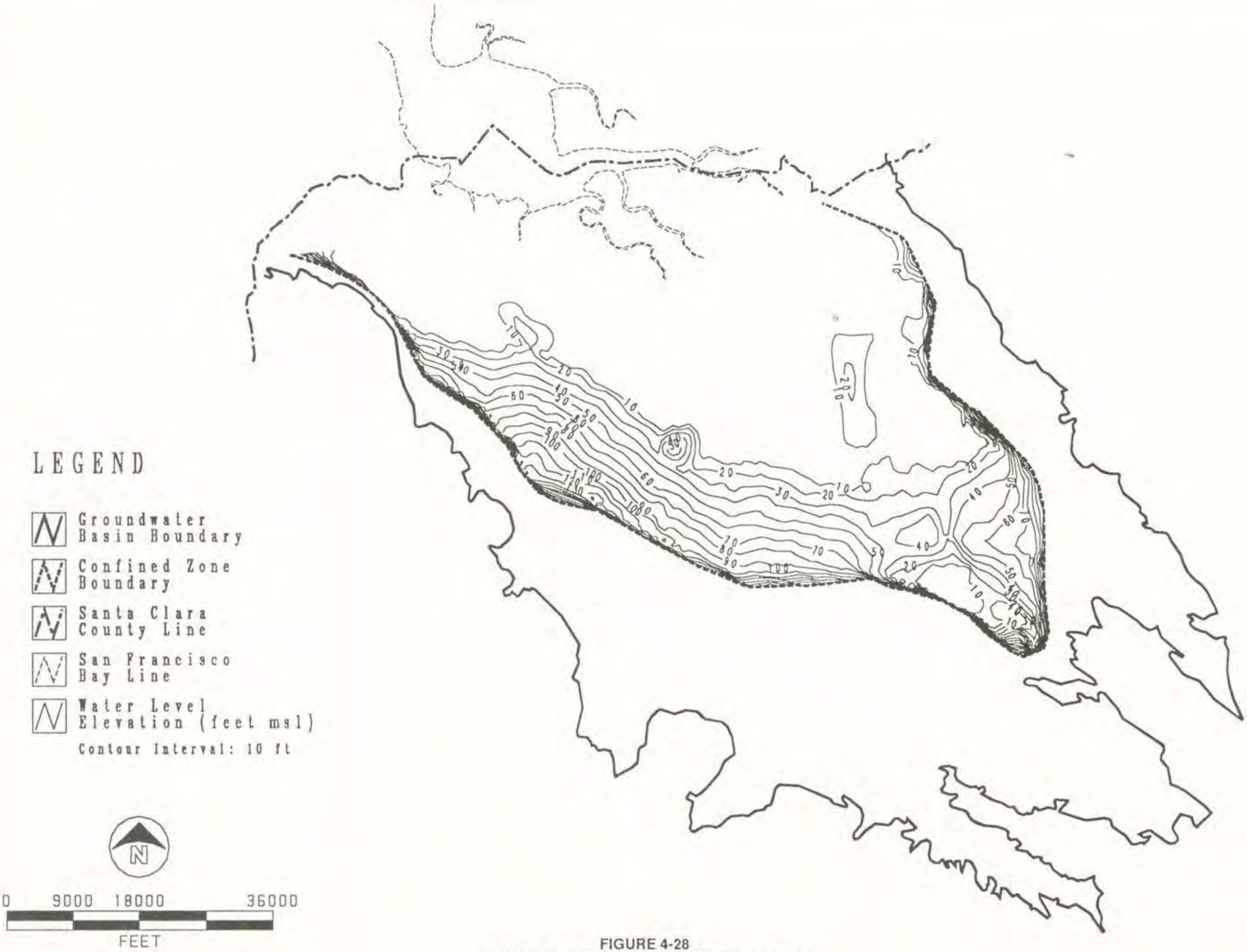


FIGURE 4-28
INITIAL HEAD DISTRIBUTION, MODEL LAYER 1

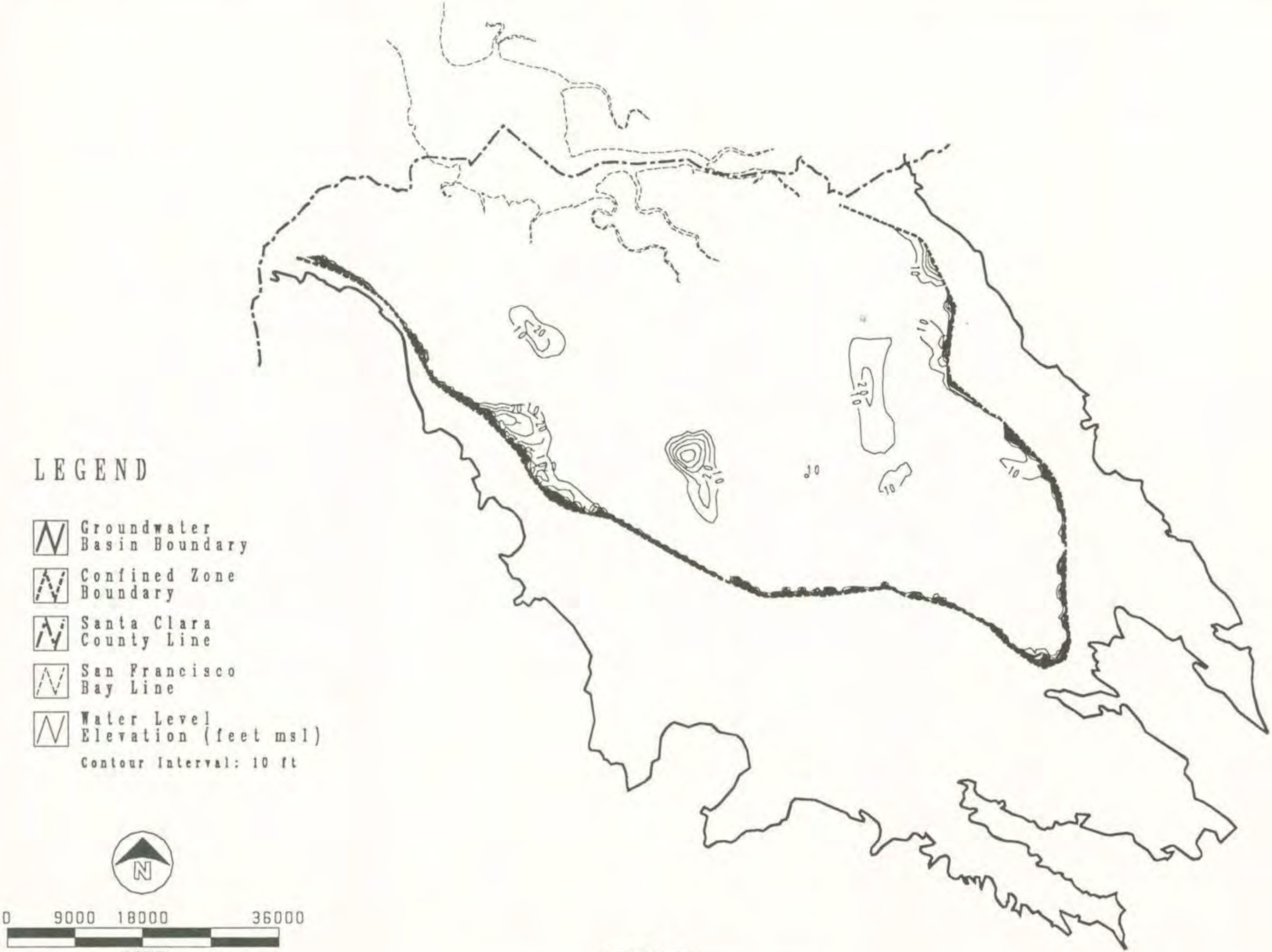


FIGURE 4-29
INITIAL HEAD DISTRIBUTION, MODEL LAYER 2

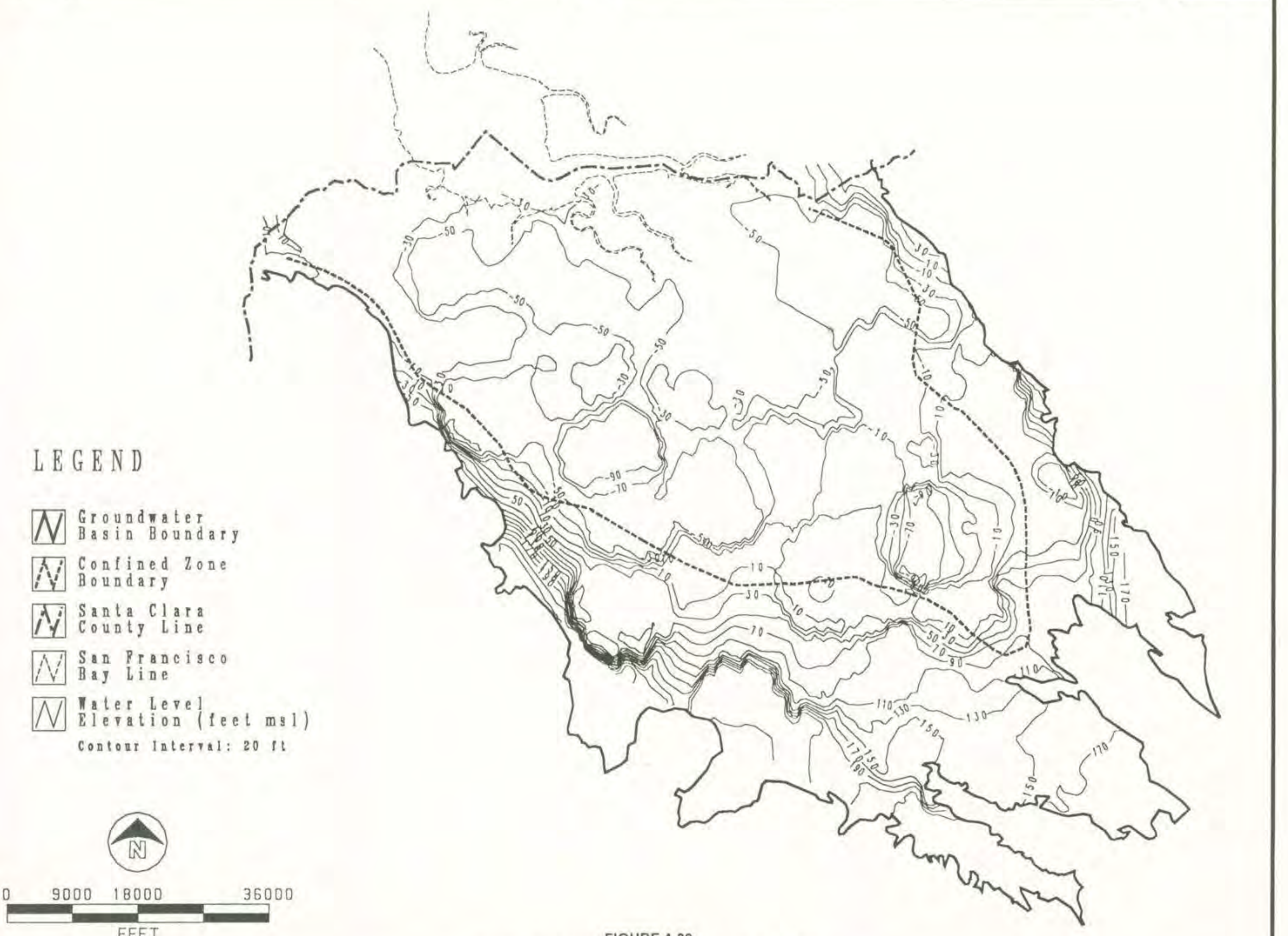


FIGURE 4-30
INITIAL HEAD DISTRIBUTION, MODEL LAYER 3

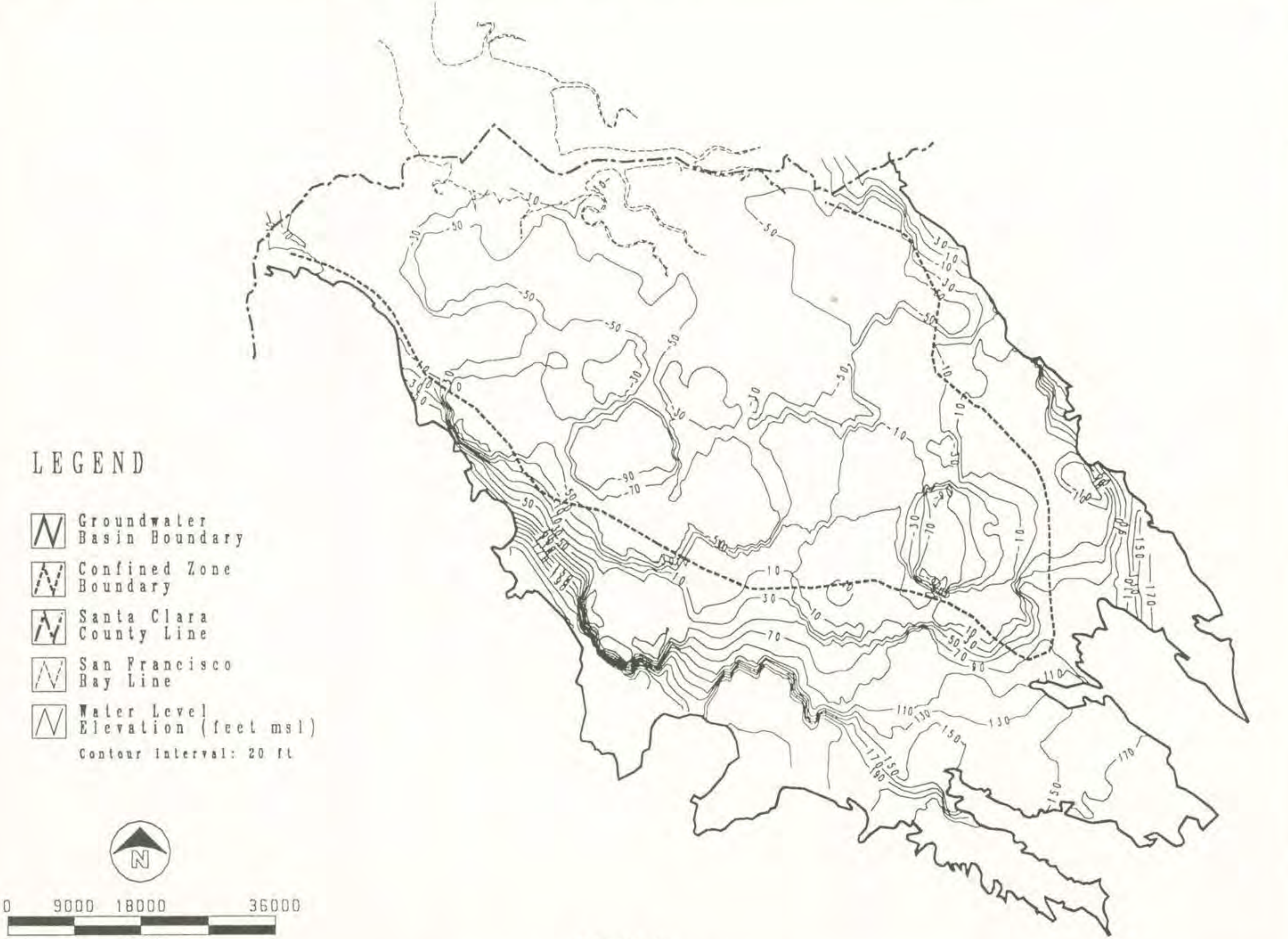


FIGURE 4-31
INITIAL HEAD DISTRIBUTION, MODEL LAYER 4

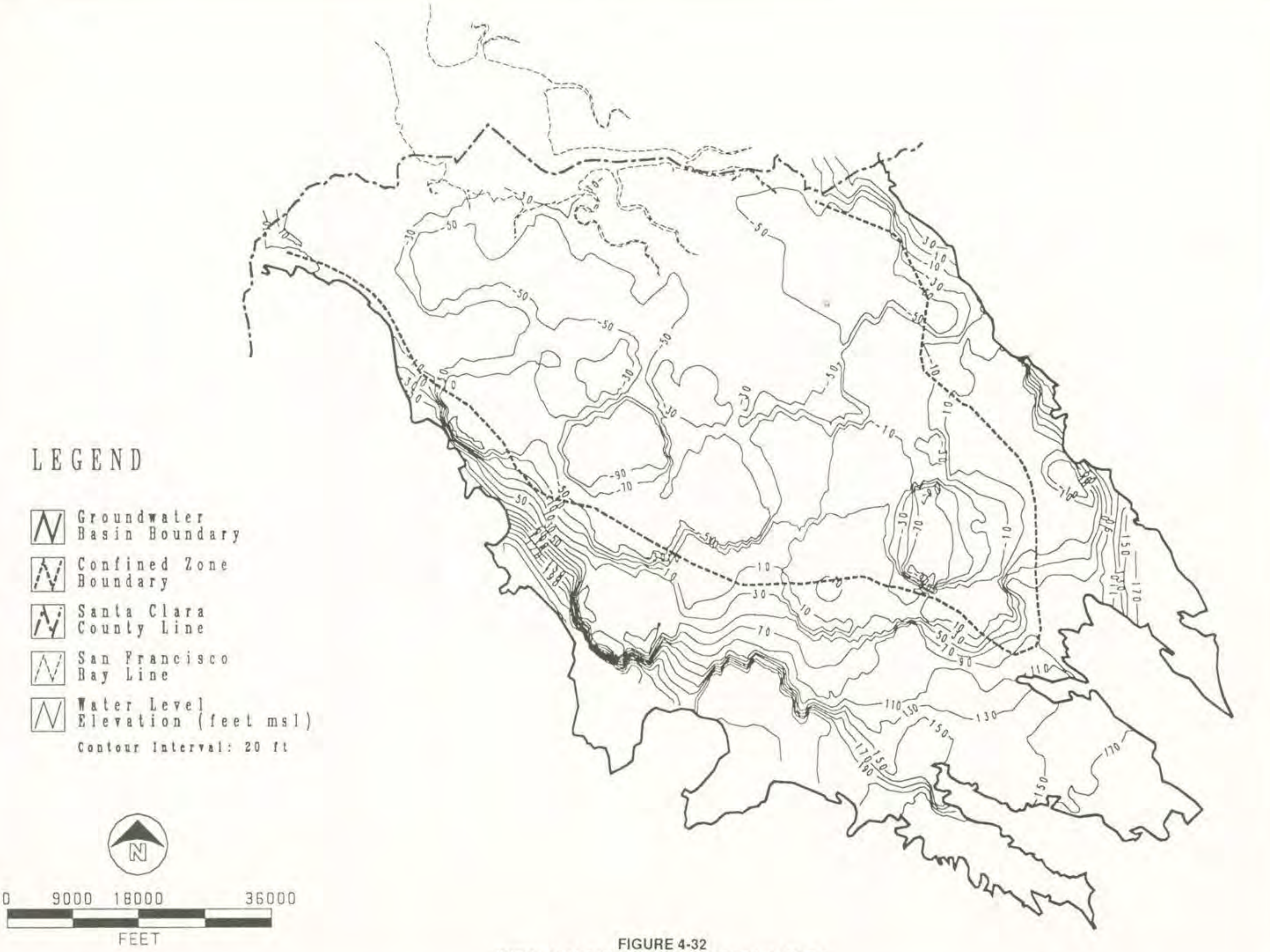


FIGURE 4-32
INITIAL HEAD DISTRIBUTION, MODEL LAYER 5

Section 5
Numerical Model Calibration and Verification

Calibrating the numerical model involved successive attempts to match model output to measured data. Modeled hydraulic heads, flows across model boundaries, and hydraulic gradients were compared against available measured data during calibration. The match between model results and measured data was improved during each successive attempt by adjusting the values of model input parameters. The model was considered calibrated when model results matched the measured data within an acceptable measure of accuracy.

Verifying the numerical model involved comparing model results to a set of measured data that were not used during calibration; hydraulic heads, flows across model boundaries, and hydraulic gradients from a time period not included in the calibration period.

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5.1 Model Calibration

The numerical model was calibrated in two steps: first, to quasi-steady state hydrologic conditions; and second, to transient hydrologic conditions. The two-step approach allowed a preliminary estimation of hydraulic conductivity and water balance component values during the steady state calibration, followed by refinement of those parameter values and an estimation of storage parameters during the transient calibration. For the Santa Clara Valley Basin numerical model, steady state calibration is very preliminary because the groundwater basin has not been under steady state conditions during recorded history.

5.1.1 Calibration Periods

Steady state and transient calibration periods were selected based on representative hydrographs and water budgets. Hydrographs representative of groundwater conditions across the basin were presented on Figure 4-16 of the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a).

5.1.1.1 Steady State Calibration

For a steady state calibration period, the piezometric surfaces, groundwater recharges, and groundwater discharges should be relatively constant. As shown by the hydrographs presented in the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a), water levels have trended either up or down during most of the period of record; especially distinct water level trends and fluctuations are apparent between 1920 and the mid 1970s. The period from 1920 to

1975 was therefore not selected for steady state calibration. The basin groundwater level fluctuations between 1920 and 1975 were caused mainly by pumping. A period of relatively few anthropogenic stresses would potentially be closer to steady state conditions. Before 1920, the basin was in an approximate steady state condition of relatively minor pumping and natural recharge (probably more so than the period after 1975). Estimated annual facility recharge and pumping for potential steady state periods (1917 and the period between 1975 and 1989) are tabulated in Table 5-1.

Although the basin appears to be under steady state conditions before 1920, data after 1975 are more accurate and complete than data from before 1920. Therefore, the years between 1975 and 1989 were examined for periods when the basin appeared to operate under approximate steady state conditions. Figure 5-1 displays estimates provided by the SCVWD of annual pumping, facility recharge, and change in storage between 1975 and 1989. As shown, between 1978 and 1982, groundwater pumping and facility recharge remained relatively constant, and the basin's change in storage fluctuated around an average value of 24,000 acre-feet. The period between calendar years 1978 and 1982 was, therefore, selected for steady state calibration.

5.1.1.2 1917 Simulation

Artesian wells covered large portions of the Santa Clara Valley before the extensive municipal development of the basin. As a check on the conceptual model and rough parameters estimated during steady state calibration, a simulation of the artesian conditions was attempted before transient calibration. Because actual artesian pressures are unknown, the purpose of this simulation was to reproduce artesian conditions in the general area covered by artesian wells. Pumping data from 1917 was estimated from a USGS study of the Santa Clara Valley (Clark, 1924).

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5.1.1.3 Transient Calibration

Four criteria were used to identify the appropriate time period for transient calibration. First, the transient calibration period must have included substantial hydraulic stresses on the groundwater basin. Second, subsidence must not have occurred during the transient calibration period (because MODFLOW cannot account for water released from subsidence). Third, the transient calibration period should be as long as possible to test a range of hydrologic conditions. Fourth, a verification period other than the transient calibration period must be available. Using these four criteria, the period between 1970 and 1983 was selected as the transient calibration period. The 1970 to 1983 period did not contain periods of subsidence (which ceased in 1969), did include the 1976 to 1977 drought and the wet 1982 to 1983 periods, and did allow for a verification period between 1984 and 1989.

Table 5-1
Annual Basin Stresses During Steady State Conditions

Year	Pumping (acre-feet per year)	Facility Recharge (acre-feet per year)
1917	~42,000[b]	None
1975[a]	138,250	92,070
1976[a]	179,370	78,730
1977[a]	136,880	32,040
1978[a]	137,240	104,650
1979[a]	152,420	88,310
1980[a]	146,300	95,850
1981[a]	162,320	83,130
1982[a]	142,410	103,950
1983[a]	154,770	100,920
1984[a]	180,340	82,860
1985[a]	181,510	76,730
1986[a]	175,720	105,750
1987[a]	172,160	83,980
1988[a]	157,810	63,110
1989[a]	88,630	91,180

[a] CH2M HILL, 1992a (Table 4-7).
[b] Clark, 1924.

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5.1.2 Calibration Data

Because available water level data are collected mainly from production wells perforated at several depth intervals, they do not necessarily correspond to individual model layers. Additionally, because the frequency and methods for collecting water level data are inconsistent throughout the basin, the data are of varying reliability. In an effort to remove the more unreliable data, only selected water level data were used to build, calibrate, and verify the model. Data that were not used included water levels from wells that pumped a "substantial" amount of water (see Section 4.5), or water levels from wells whose hydrographs did not have a reasonable length of record. Of the approximately 6,000 wells documented in the Santa Clara Valley Basin, only 343 wells had water levels that were not from "substantial" pumping wells. The 343 wells are listed in Appendix C.

The 343 wells were further screened by using only wells with a period of record that spanned at least 4 years during the model calibration period (1970 through 1983). Additionally, wells with hydrographs that did not appear representative of local piezometric conditions (hydrographs grossly different than hydrographs of nearby wells) were screened out.

Using available well completion information for the selected wells, perforated screened intervals were compared to model layers, and wells that were generally perforated across only one model layer were assigned to that model layer. For wells that were perforated across multiple model layers, hydrographs were compared with hydrographs of nearby wells for which a model layer had been assigned. Wells perforated across several model layers were then assigned to the same model layer as nearby wells that had similar hydrographs.

5.1.3 Conceptual Model Revisions

Preliminary calibration results suggested necessary changes to the initial model constructed around the conceptual model presented in the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a) and in Chapter 4. The following paragraphs discuss changes to the conceptual model that were made during calibration of the numerical model.

5.1.3.1 Model Layers

The areal extent of the major confining layer (Model Layer 2) was reduced during calibration. Initially, the extent of the confined zone as interpreted by the SWRCB (1955) was used for Model Layer 2. During calibration, hydrographs from wells on the west and southwest portions of the confined zone were more easily simulated by the numerical model without the low-permeability confining zone. The major

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confining unit extent was, therefore, decreased to match the low-permeability aquitard shown in the hydrostratigraphic map of depth region 2 presented in the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a). Figure 5-2 shows the original and revised extent of the major confining unit (Model Layer 2).

The simulated water table on the west side of the basin dipped below the bottom of Model Layer 1, into Model Layer 2 during early calibration efforts. This dipping water table caused convergence problems in the model because model cells in Model Layer 1 were going dry. Because Model Layer 2 no longer simulated a confining zone near the margins of the basin, and to provide numerical stability to the model, the thickness of Model Layer 2 was reduced and the thickness of Model Layer 1 was increased outside the revised boundary of the major aquitard. The increased thickness of Model Layer 1 outside the major aquitard allows the water table to fluctuate in Model Layer 1. A cross section illustrating the resulting model layer thicknesses is presented on Figure 5-3.

5.1.3.2 Parameter Zonation

Sufficient water level data for Model Layers 1 and 2 were not available to support the initial horizontal and vertical hydraulic conductivity zonation presented in Section 4.4.1 and Figures 4-14 and 4-15. For this reason, the horizontal hydraulic conductivity zonation was changed; Model Layers 1 and 2 were changed to a single horizontal hydraulic conductivity zone and two vertical hydraulic conductivity zones (one zone to simulate the major aquitard and one zone to simulate Model Layer 2 outside the aquitard).

The specific yield of Model Layer 3 was subdivided into three specific yield zones as shown on Figure 5-4. These three zones generalize the distribution of specific yield estimated by CDWR (Figure 4-19).

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5.1.4 Steady State Calibration Results

5.1.4.1 Water Levels

Maps of steady state calibration results (groundwater levels) for Model Layers 1 through 5 are presented on Figures 5-5 through 5-9. A composite piezometric surface map using data from all five model layers is included on Figure 5-10. Model Layer 6 serves only as a source of water and was not used during calibration. Maps of individual model layer piezometric surfaces were constructed by contouring the piezometric head from each cell in the model layer. The composite map was constructed by contouring the piezometric heads from cells that correspond to some of the monitoring wells used by SCVWD in the construction of their annual piezometric surface maps (e.g., Figure 4-7), regardless of model layer (all monitoring wells used by

SCVWD could not be used because some of the well completion data were unavailable). The composite map produced with model results is roughly comparable to the annual SCVWD composite maps (e.g., Figure 4-7). Such agreement indicates that the conceptual model and general horizontal and vertical hydraulic conductivity distribution are likely correct (although hydraulic conductivities values could be refined during transient calibration).

Table 5-2 lists measured and simulated water levels for selected wells. The measured water levels are averages of all water level measurements during the period 1978 to 1982. There was no attempt to remove any measuring bias.

5.1.4.2 Water Budget

The steady state calibration water budget is included in Table 5-3. Simulated recharge and pumping were summed from the model input files. Flow to San Francisco Bay, flow from Fremont Aquifers, and flow through Coyote Narrows were calculated by printing flows to each constant head cell, identifying which cells represented each physical feature, and summing the total flow to cells representing each feature. The modeled water budget approximates the water budget estimated in Table 4-7 of the Hydrogeologic Interpretation Draft Technical Memorandum (CH2M HILL, 1992a). The discrepancy in the recharge component is compensated for by the change in storage values; the steady state model requires no change in storage. The model accounts for the average annual change in storage between 1978 and 1982 by accepting less recharge.

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5.1.5 1917 Simulation Results

The simulation was accomplished by replacing all water table cells in the model with constant head cells. The head value assigned each constant head cell was derived from Plate XII produced by Clark (1924). Groundwater discharge through pumping was added, and the model was run in steady state mode.

A map of the results of the 1917 simulation is presented on Figure 5-11. This map shows that the general area outlined by Clark as containing flowing wells is simulated roughly by the groundwater flow model.

5.1.6 Transient Calibration Results

The length of stress periods for transient calibration was a compromise among three factors: accurately simulating piezometric fluctuations, remaining generally faithful to the data accuracy, and coordinating a manageable amount of data. The first consideration requires that we accurately simulate observed fluctuations in the existing hydrographs. Virtually all hydrographs from the Santa Clara Valley Basin display

Table 5-2
Steady State Calibration Results

Well Number	Model Layer	Simulated Water Level (ft, MSL)	Measured Water Level (ft, MSL)	Difference (ft)
06S1E32MO5	1	66.49	33.71	+32.8
06S1W35K01	2	43.52	10.76	+32.8
05S2W32F10	3	-12.75	-4.82	-7.9
06S1E29G06	3	-39.15	31.36	-70.5
06S2W03N01	3	-34.79	-14.94	-19.9
06S2W05F03	3	-18.20	-2.55	-15.7
06S2W13F01	3	-50.89	-24.99	-25.9
06S3W13A10	3	-1.98	11.94	-13.9
07S1E06L01	3	-45.26	11.21	-56.5
07S1E07R99	3	-33.65	36.68	-70.3
07S1W02G01	3	-53.91	0.22	-54.1
08S1E02R01	3	172.29	136.07	+36.2
08S1E10J01	3	164.81	141.07	+27.7
08S1E11Q01	3	179.69	144.59	+35.1
08S1E15C02	3	171.52	141.03	+30.5
08S1W11R01	3	230.65	224.33	+6.3
07S1E10P01	4	-29.72	-26.56	-3.2
07S1E07F01	5	-48.33	-28.77	-19.6
07S1W21A01	5	-16.90	5.1	-22.0

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Table 5-3
Comparison of Simulated and Estimated Steady State Water Budget

Water Budget Component		Simulated Flow 1978-82 (Acre-feet)	Estimated Flow[a] 1978-1982 (avg) (Acre-feet)	Percent Difference
Inflows	Flow through Coyote Narrows	6,920	5,000	+38%
	Recharge from rainfall, delivered water, mountain-front, and facility recharge	139,958	164,500[b]	-15%
	Flow from Fremont Aquifers	2,443	3,000	-19%
Outflows	Pumping	147,349	148,100	-1%
	Flow to San Francisco Bay	1,978	No Estimate	N/A
Change in Storage		0	24,400	N/A

[a] CH2M HILL, 1992a (Table 4-7).

[b] The sum of "facility recharge" and "balance of terms" from Table 4-7 of the HI TM, less flows through Coyote Narrows and Fremont Aquifers.

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regular seasonal fluctuations, thereby requiring seasonal stress periods. Many hydrographs are based on monthly piezometric readings, suggesting that monthly stress periods could be accurately calibrated. The second consideration constrains the assumptions imposed on raw data. Pumping data are only completely accurate for semi-annual stress periods, because data were furnished by 6-month totals. Potential error is introduced when the pumping was divided into monthly estimates as described in Section 4.6.1.1. The final consideration was data and output quantity; monthly stress periods require roughly three times the data input as quarterly stress periods, and result in a correspondingly larger output. Based on these three considerations, the 14-year transient calibration period (1970-1983) was simulated with 56 stress periods of 3 months each.

Successive simulations were attempted with different MODFLOW solving packages. From results of these simulations, the preconditioned conjugate gradient solver (Hill, 1990) was chosen. After attempting simulations with different combinations of solver parameters, the following parameters were chosen: a maximum of 90 outer iterations, a maximum of 30 inner iterations, the modified incomplete chlolesky preconditioning, a head change criterion of 0.01 foot, a flow criterion of 10 ft^3/day, a relaxation parameter of 0.97, five time steps per stress period, and a time step multiplier of 2.

Table 5-4 lists the final calibrated parameter values for the numerical model. As noted in Section 5.1.3, revisions to the original conceptual model allowed for fewer parameters in the final calibration during transient calibration. The calibrated horizontal hydraulic conductivity distributions (zones) for Model Layer 3 are mapped on Figure 5-12. Model Layers 4 and 5 have identical horizontal hydraulic conductivity distributions, which are mapped on Figure 5-13. No maps are prepared for Model Layers 1 and 2, because they both comprise a single horizontal hydraulic conductivity value.

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5.1.6.1 Water Levels

Hydrographs illustrating results of the transient calibration are included on Figures 5-14 through 5-18. Maps showing the locations of the hydrographs are displayed on Figures 5-19 through 5-23. The general rising trend in water levels during the calibration period, along with the general magnitude of hydrograph fluctuations, are reasonably well reproduced by the calibrated, transient numerical model.

Simulated hydrographs for wells in the Santa Teresa Basin follow the trend of the measured hydrographs, but do not show the fluctuations of the measured hydrographs (see Figures 5-16d and 5-16e for hydrographs of wells 08S1E02R01, 08S1E05N01, 08S1E10J01, 08S1E11Q01, 08S1E15C02, and 08S1W11RO1). Measured hydrographs display the semi-confined response of wells completed at multiple depths. The Santa

Table 5-4
Calibrated Model Parameter Values

Parameter	Model Layer and Zone Number	Value
Horizontal Hydraulic Conductivity	Layer 1	70 ft/day
	Layer 2	10 ft/day
	Layer 3, Zone 1	30 ft/day
	Layer 3, Zone 2	30 ft/day
	Layer 3, Zone 4	100 ft/day
	Layer 3, Zone 5	5 ft/day
	Layer 3, Zone 6	7 ft/day
	Layers 4 and 5, Zone 1	10 ft/day
	Layers 4 and 5, Zone 2	20 ft/day
	Layers 4 and 5, Zone 3	55 ft/day
	Layers 4 and 5, Zone 4	5 ft/day
Vertical Hydraulic Conductivity	Layer 1, Zone 1	0.05 ft/day
	Layer 1, Zone 2	0.005 ft/day
	Layer 2, Zone 2	0.0005 ft/day
	Layers 3, 4, and 5	0.03 ft/day
Storage	Layers 1 and 2 Specific Yield	0.07
	Layer 2 Storativity	0.001
	Layers 3, 4, and 5 Storativity	0.0001
	Layer 3 Specific Yield, Zone 1	0.02
	Layer 3 Specific Yield, Zone 2	0.11
	Layer 3 Specific Yield, Zone 3	0.07
Total Number of Parameters = 21		

Teresa basin was modeled as a single unconfined layer (Model Layer 3). Hydrographs from the single, unconfined layer display the correct water table surface, but can not show the piezometric fluctuations of a semi-confined aquifer.

Maps of the calibrated piezometric surfaces for Model Layers 1 through 5 are included on Figures 5-24 through 5-28. A composite piezometric surface map for autumn 1981 water levels is included on Figure 5-29. As discussed previously, piezometric surface maps of individual model layers were constructed by contouring the piezometric heads from each cell in the model layer. The composite piezometric surface map was constructed by contouring piezometric head from cells that correspond to some of the monitoring wells used by SCVWD to construct their annual composite maps, regardless of model layer (all monitoring wells used by SCVWD could not be used because some of the well completion data were unavailable). The apparent pumping depression that appears in the annual SCVWD piezometric surface maps beneath San Jose is evident in the composite map produced using the model results. This apparent pumping depression had not been successfully reproduced in previous modeling efforts (Bredehoeft, 1992). Because the apparent pumping depression simulated by the current numerical model is an artifact of combining multiple piezometric surfaces into a single map, it supports the conceptual model of multiple piezometric surfaces within the confined zone.

5.1.6.2 Water Budget

The water budget from the calibrated transient model is compared to the steady state water budget and the water budget in the Hydrogeologic Interpretation Draft Technical Memorandum in Figures 5-30 through 5-34. The graphs show that the transient water balance is similar to the estimated water balance, although some differences exist.

Figure 5-30 displays the four components of the water balance printed in the MODFLOW output: water released from storage, water flowing from constant head cells, water pumped by wells, and water introduced through the recharge matrix. Positive values indicate water flowing into the basin (such as recharge); negative values indicate water leaving the basin (such as pumping). Figure 5-30 shows that water flowing through constant head cells is small compared to the other components of the water budget. The constant head cells simulate San Francisco Bay, connections with the Fremont Aquifers, and the Coyote Narrows.

Figures 5-31 through 5-34 compare results from the calibrated transient simulation, steady state simulation, and estimate from the Hydrogeologic Interpretation Technical Memorandum for each of the four water budget components. As stated in Section 5.1.4.2, the discrepancy between the estimated recharge and the steady state simulated recharge is due to the necessary discrepancy in the storage component.

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Figure 5-34 indicates that the amount of water flowing to San Francisco Bay in the model is greater than anticipated. After 1978, the model shows a net loss of groundwater to the constant head cells. This may be partially due to the over-estimation of percolation due to rainfall in the confined zone, mentioned in Section 4.6.2. To remove the excess groundwater above the confined zone, high conductivities were incorporated into Model Layer 1. The high conductivities result in much of the estimated recharge from rainfall in Model Layer 1 flowing into San Francisco Bay.

5.1.6.3 Calibration Criteria

Calibration criteria for the numerical model were designed to help determine when a reasonable match between transient model results and actual data for hydraulic heads had been achieved. These criteria were grouped by the susceptibility of areas within the basin to subsidence. The zones for which calibration criteria were defined were: the recharge zone (outside the confined zone boundary); a "critical subsidence zone" (delineated by the line of 4 feet of subsidence as interpreted by Poland (1969 and 1988)); and a transition zone between the confined zone boundary and the "critical subsidence zone" (Figure 5-35). Table 5-5 lists the calibration criteria proposed by the SCVWD (the criteria are the difference between each simulated and measured groundwater level at selected wells).

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Table 5-5
SCVWD Transient Calibration Criteria

Zone	Calibration Criteria
Recharge Zone	<5 feet
"Critical Subsidence Zone"	<10 feet
Transition Zone	<20 feet

5.1.6.4 Evaluation of Transient Calibration

Simulated water levels were compared to measured water levels using SCVWD calibration criteria. Model results from the summer and winter quarters (i.e., the transition periods between hydrograph peaks) were used for the evaluation. Assuming that the model results represent groundwater conditions at the end of each quarter, simulated heads were compared to water level data collected within 2 weeks on either side of June 30 and December 31. The difference between the simulated and measured water levels were then compared against the SCVWD criteria. The results of this comparison are presented in Table 5-6. Scattergrams showing the relationship between

Table 5-6
Comparison of SCVWD Criteria and Model Results

Model Layer and Zone	Representative Wells	SCVWD Criteria	Percentage of Model Results That Match SCVWD Criteria[a]
Layer 1	06S1E32MO5	<20 feet	100%
	06S2W22H04	<20 feet	100%
Layer 2	06S1W22H01	<10 feet	100%
	06S1W35K01	<10 feet	78%
Layer 3, Zone 1	06S1E29G06	<20 feet	57%
Layer 3, Zone 2	06S1W21J01	<10 feet	70%
	06S2W03N01	<20 feet	94%
	06S2W13F01	<10 feet	66%
	07S1W02G01	<10 feet	70%
Layer 3, Zone 4	07S1E06L01	<10 feet	71%
	07S1E07R99	<10 feet	76%
	08S1E02R01	<5 feet	75%
	08S1E05N01	<5 feet	66%
	08S1E10J01	<5 feet	85%
	08S1E11Q01	<5 feet	83%
	08S1E15C02	<5 feet	68%
Layer 3, Zone 5	05S2W32F10	<20 feet	100%
Layer 3, Zone 6	06S2W05F03	<20 feet	100%
	06S3W13A10	<20 feet	100%
	07S1W07K01	<20 feet	100%
	08S1W11R01	<5 feet	75%
Layer 4, Zone 1	07S1W33L01	<20 feet	89%
Layer 4, Zone 2	07S2W12M01	<20 feet	75%
Layer 4, Zone 3	07S1E10P01	<10 feet	68%
Layer 5, Zone 1	07S1W17E01	<20 feet	89%
	07S1W21A01	<20 feet	78%
Layer 5, Zone 2	06S1W24K02	<20 feet	71%
Layer 5, Zone 3	07S1E07F01	<10 feet	71%

[a] For instance if 10 out of 28 water levels can be compared for the well during the calibration period, and 7 of those 10 meet the criterion, the % = 70%.

simulated and measured water levels for each well listed in Table 5-6 are included in Appendix D.

Possible reasons for the differences between simulated and measured water levels include the discretization of time and space in the numerical model. A series of calculations were undertaken to evaluate potential model errors resulting from discretization. Potential effects of both spatial discretization (size of the model cells) and temporal discretization (length of the modeled stress periods) were investigated. The results of these calculations are provided in Appendix E; the calculations illustrate that the difference between simulated and measured water levels could be as much as 20 feet or more for a confined-zone well and about 5 feet or less for a recharge-zone well.

Linear regressions were performed as a statistical measure of the relationship between the simulated and measured water level data. One regression was performed for each horizontal hydraulic conductivity zone. Confidence intervals and prediction intervals were calculated for these regressions, each with a significance level of 95 percent. Table 5-7 summarizes the results of the statistical analyses; graphical presentations are presented in Appendix F. The range of confidence interval values, listed in Table 5-7, for each parameter zone reflects the curvature of the confidence interval bands. Low- and high-confidence band widths are measured within the range of available data for each zone. Many of the prediction intervals have only one value because the prediction interval bars are essentially parallel over the range of available data. Similar statistics were calculated for the results of individual wells, one from each horizontal hydraulic conductivity zone.

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When errors between measured and simulated water levels are randomly distributed about the regression line (i.e., they are normally distributed about the regression line), the model results may be interpreted to be unbiased. The assumption of normal residuals around the regression line was tested for each zone using a Chi-squared test and a Kolmogorov-Smirnov test. In these two tests, a measure of confidence was assigned to the hypothesis that the residuals were normally distributed about the regression line (called the null hypothesis). If the hypothesis can be rejected, the residuals might not be normally distributed. Table 5-7 lists whether the null hypothesis can be rejected for both the Chi-squared and Kolmogorov-Smirnov tests with a significance level of 0.1 (90 percent confidence).

5.2 Verification Results

Model verification is an indication of the predictive ability of the model. Verification consists of running the model for a time period not used during calibration; the predictive ability of the model is indicated by the models ability to simulate measured heads

Table 5-7
Summary of Confidence Intervals for Transient Calibration

Model Layer and Zone	95 Percent Confidence Interval	95 Percent Prediction Interval	Representative Wells	95 Percent Confidence Interval for Representative Well	95 Percent Prediction Interval for Representative Well	Reject Normality Hypothesis with $\alpha=0.1$ using Chi-squared test?	Reject Normality Hypothesis with $\alpha=0.1$ using Kolmogorov-Smirnov test?
Layer 1	±1 foot to ±3 feet	±15 feet	06S1E32MO5	±2.5 feet to ±4.5 feet	±10 feet	No (but close)	No
Layer 2	±1.5 feet to ±5.5 feet	±15 feet	06S1W22H01	±3 feet to ±6 feet	±7.5 feet to ±10.5 feet	No	No
Layer 3, Zone 1	±2 feet to ±10 feet	±50 feet	06S1E29G06	±7 feet to ±30 feet	±35 feet	No	No
Layer 3, Zone 2	±2 foot to ±9 feet	±35 feet	06S1W21J01	±4 feet to ±7 feet	±10 feet	No	No
Layer 3, Zone 4	±0.5 feet to ±2 feet	±35 feet	08S1E10J01	±1 foot to ±3.5 feet	±8 feet	Yes	Yes
Layer 3, Zone 5	±2.5 feet to ±6 feet	±12.5 feet	05S2W32F10	±2 feet to ±4.5 feet	±7.5 feet	Yes	No
Layer 3, Zone 6	±3 feet to ±8 feet	±55 feet	06S2W05F03	±2 feet to ±4 feet	±7 feet	Yes	Yes
Layer 4, Zone 1	±5 feet to ±13 feet	±40 feet	07S1W33L01	±4 feet to ±10 feet	±12.5 feet	No	No
Layer 4, Zone 2	±6 feet to ±10 feet	±12.5 feet	07S2W12M01	±6 feet to ±10 feet	±12.5 feet	Insufficient data	Insufficient data
Layer 4, Zone 3	±3 feet to ±7 feet	±27 feet	07S1E10P01	±3.5 feet to ±7.4 feet	±15 feet	No	No
Layer 5, Zone 1	±4 feet to ±15.5 feet	±34 feet	07S1W17E01	±5 feet to ±10 feet	±15 feet	No	No
Layer 5, Zone 2	±5 feet to ±9 feet	±12.5 feet	06S1W24K02	±2.5 feet to ±3.5 feet	±6 feet	No	No
Layer 5, Zone 3	±4 feet to ±10 feet	±34 feet	07S1E07F01	±7 feet to ±16 feet	±37.5 feet	No	No

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not used in calibration. Requirements of the verification period include adequate data, no subsidence, and independence from the calibration period. The period between 1984 and 1989 was used for verification of the numerical model because these are the only years without subsidence that were not used for calibration.

Where possible, the same wells used for water level data during transient calibration were used during verification. However, because many of the wells used for calibration do not have water level measurements that extend into the verification period, water levels for several new wells were evaluated during verification. Locations of the verification wells are presented on Figures 5-36 through 5-40. Verification hydrographs are presented on Figures 5-41 through 5-45.

Hydrographs over the verification period show the moderately good predictive ability of the model. The downward water level trend resulting from the relatively dry conditions between 1984 and 1990 is reproduced by the model. Hydrographs of wells near Sunnyvale accurately simulate the sharp piezometric decline in 1988 (see Figures 5-42, 5-43b, and 5-43c for hydrographs from wells 06S3W12R10, 06S2W05FO3, and 06S3W01M10). Simulated hydrographs for Model Layers 3, 4, and 5 generally match the measured water level fluctuations except for the low water levels recorded in 1988 near San Jose (see Figures 5-43b, 5-43c, 5-43d, and 5-44 for hydrographs from wells 06S1W24H08, 06S1W35L01, 07S1E06L01, 07S1E07R99, and 07S1W22N02).

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The verification results were compared to the SCVWD calibration criteria (Table 5-5). Table 5-8 lists the percentage of model verification results that meet the appropriate SCVWD criteria. Statistical analyses similar to those performed for calibration results were also conducted using the verification results. The results of statistical analyses performed on the verification results are summarized in Table 5-9.

5.3 Conclusions

A groundwater model of the Santa Clara Valley Basin has been constructed and calibrated that simulates the major features of groundwater flow in the basin. As with all numerical models, the model's purpose, discretization, and level of calibration dictate appropriate model uses.

Because the groundwater model covers the entire Santa Clara Valley basin, the model is better suited to answer questions regarding basinwide concerns than localized concerns. Examples of basinwide investigations suitable for studying with the groundwater flow model may include: basinwide water level effects of redistributing pumping centers within the basin, basinwide water level effects of redistributing recharge within the basin, and investigating potential increases or decreases in

Table 5-8
Comparison of SCVWD Criteria and Model Results Verification Simulation

Layer and Zones	Representative Wells	SCVWD Criteria for Each Well	Percentage of Model Results That Match SCVWD Criteria
Layer 1	06S1E06P02	<20 feet	100%
	06S1E17Q01	<20 feet	38%
	06S1E31E01	<10 feet	33%
Layer 2	06S1E18K01	<20 feet	100%
	06S1W35K01	<10 feet	100%
	06S3W12R10	<20 feet	100%
Layer 3, Zone 1	06S1E06N01	<20 feet	64%
	06S1E15Q01	<5 feet	18%
Layer 3, Zone 2	06S1W24H08	<20 feet	100%
	06S2W03N01	<20 feet	100%
	06S2W10G02	<10 feet	100%
	07S1W02G01	<10 feet	75%
Layer 3, Zone 4	07S1E06L01	<10 feet	82%
	07S1E07R99	<10 feet	67%
	07S1E21A02	<10 feet	88%
	08S1E05N01	<5 feet	42%
	08S1E11Q01	<5 feet	25%
	08S2E17N01	<5 feet	50%
	08S1E27C02	<5 feet	90%
Layer 3, Zone 5	05S2W32F10	<20 feet	100%
	06S1W05L02	<10 feet	75%
Layer 3, Zone 6	06S2W05F03	<20 feet	100%
	06S3W01M10	<20 feet	100%
Layer 4, Zone 3	07S1E10P01	<10 feet	75%
	07S1E22N02	<10 feet	75%
Layer 5, Zone 1	07S1W28R01	<20 feet	86%
Layer 5, Zone 3	07S1E07F01	<10 feet	63%

Table 5-9
Summary of Confidence Intervals for Verification Simulation

Layer and Zone	95 Percent Confidence Interval	95 Percent Prediction Interval	Representative Wells	95 Percent Confidence Interval for Representative Well	95 Percent Prediction Interval for Representative Well	Reject Normality Hypothesis with $\alpha=0.1$ using Chi-squared test?	Reject Normality Hypothesis with $\alpha=0.1$ using Kolmogorov-Smirnov test?
Layer 1	±2.5 feet to ±3.5 feet	±10 feet	06S1E06P02	±0.5 foot to ±1.5 feet	±4 feet	Yes	Yes
Layer 2	±2 feet to ±5 feet	±8 feet to ±10 feet	06S3W12C10	±1.5 feet to ±3 feet	±4.5 feet	No	No
Layer 3, Zone 1	±8.5 feet to ±13 feet	±31 feet	06S1E06N01	±5 feet to ±18 feet	±17 feet	No	No
Layer 3, Zone 2	±2.5 feet to ±7 feet	±13 feet	06S2W10G02	±1.5 feet to ±3.5 feet	±5 feet	No	No
Layer 3, Zone 4	±1 foot to ±5 feet	±20 feet	08S1E11Q01	±2 feet to ±4.5 feet	±6 feet	No	No
Layer 3, Zone 5	±2.5 feet to ±5 feet	±13 feet	05S2W32F10	±0.5 feet to ±1.5 feet	±4 feet	Yes	No
Layer 3, Zone 6	±4 feet to ±9 feet	±25 feet	06S2W05F03	±0.5 foot to ±2.5 feet	±3 feet	Yes	Yes
Layer 4, Zone 3	±5 feet to ±10 feet	±20 feet	07S1E10P01	±5 feet to ±10 feet	±17 feet	No	No
Layer 5, Zone 1	±8 feet to ±17 feet	±35 feet	07S1W28R01	±12.5 feet to ±25 feet	±31 feet to ±40 feet	No	No
Layer 5, Zone 3	±5 feet to ±14 feet	±24 feet	07S1E07F01	±7.5 feet to ±16 feet	±20 feet	No	No

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groundwater storage under different management scenarios. Localized concerns, such as water levels in particular wells, can be estimated with the model, however, some error in these estimates should be expected.

One of the most effective uses of the groundwater model is to compare groundwater management scenarios. Rather than analyzing a single simulation, results from a number of simulations should be compared to determine the relative advantages of each management strategy.

The groundwater model has been calibrated to data from certain wells. As noted in Section 4.3.1, the heterogeneity of sediments in the basin can prompt wells near each other to display different water levels. Because the groundwater model cannot simulate all of the basin heterogeneity, wells not used for calibration may not be represented accurately. Therefore, caution must be exercised when interpreting data for wells that were not used for calibration.

Based on the evaluation of the differences between simulated and measured hydrographs and hydraulic gradients, the following conclusions about the numerical model of the Santa Clara Valley Basin can be made.

- The conceptual model of multiple piezometric surfaces within the confined zone, simulated with multiple model layers, appears to be appropriate.
- The model results accurately simulate general water balance trends and water level fluctuations throughout the basin.
- The model results accurately simulate groundwater levels in the heavily-pumped area near San Jose, and in the Santa Teresa Basin.
- The model results accurately simulate unconfined water table elevations in the Santa Teresa Basin, although the semi-confined response of many of the wells is not simulated by the model.
- The water budget is roughly correct in the unconfined zone.
- The water budget for Model Layer 1 (overlying the confined zone) appears to accumulate too much water. This is shown by the high conductivities necessary for Model Layer 1, and the amount of groundwater apparently flowing to San Francisco Bay.

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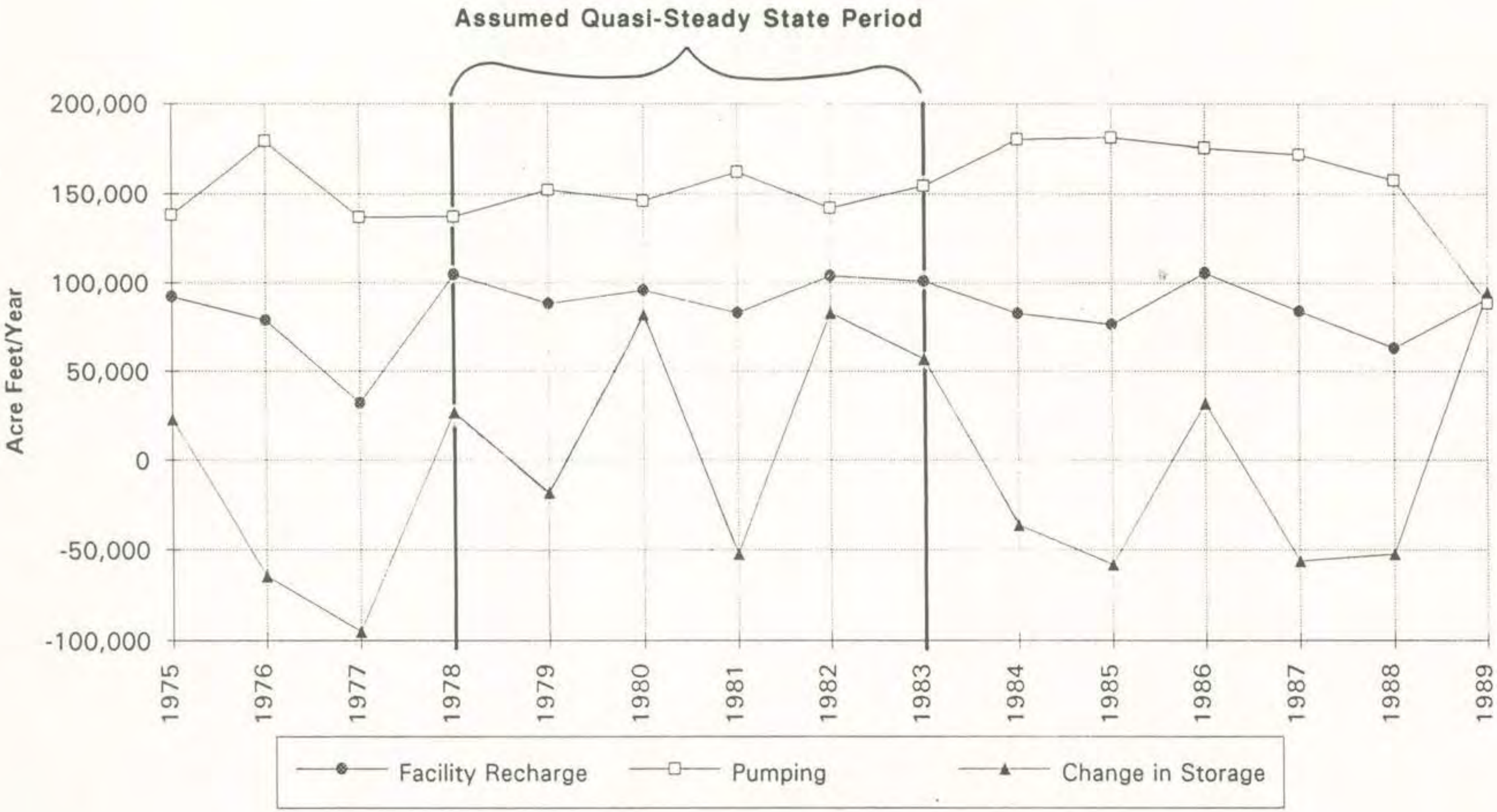


SOURCE: CH2M Hill, 1992a.

FIGURE 5-1
MAJOR WATER BUDGET COMPONENTS, 1975-1989

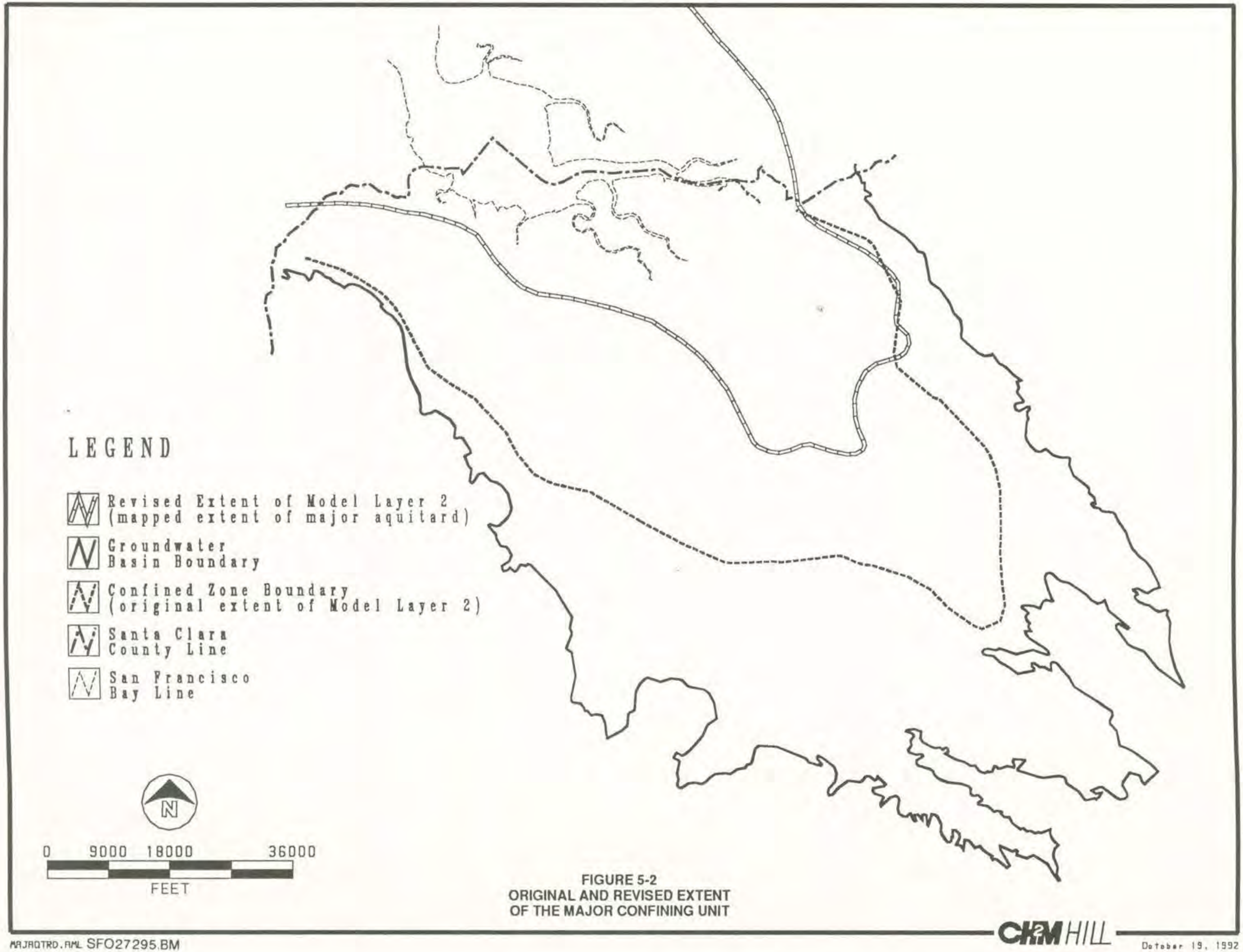
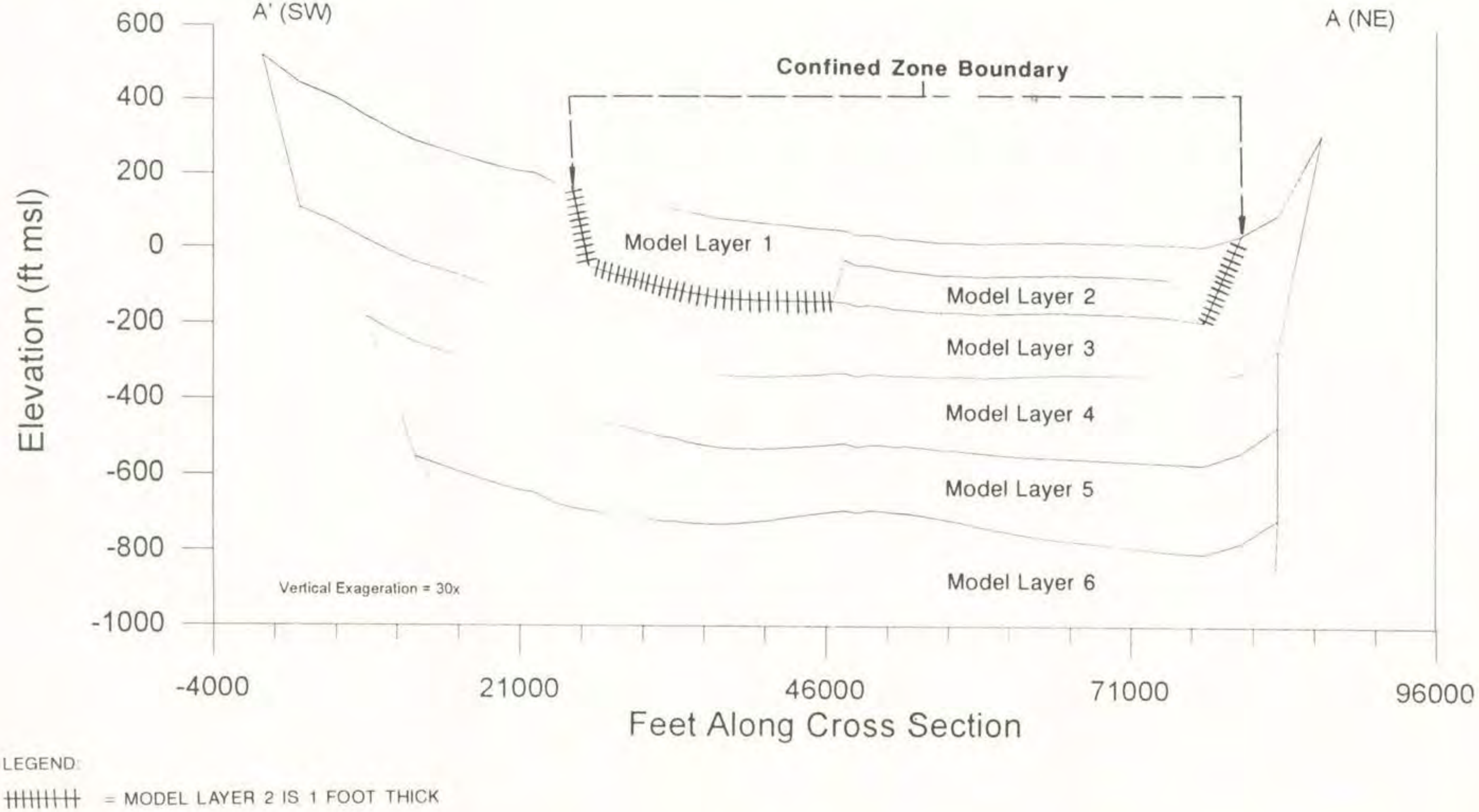

LEGEND
Revised Extent of Model Layer 2 (mapped extent of major aquitard)
Groundwater Basin Boundary
Confined Zone Boundary (original extent of Model Layer 2)
Santa Clara County Line
San Francisco Bay Line
N
0 9000 18000 36000
FEET

FIGURE 5-2
ORIGINAL AND REVISED EXTENT
OF THE MAJOR CONFINING UNIT

MAJAQTRD.AML SFO27295.BM

CH2M HILL

October 19, 1992



NOTE: SEE FIGURE 4-10 FOR LOCATION OF
CROSS SECTION A-A'

FIGURE 5-3
CROSS SECTION A-A'
REVISED NUMERICAL MODEL LAYERING

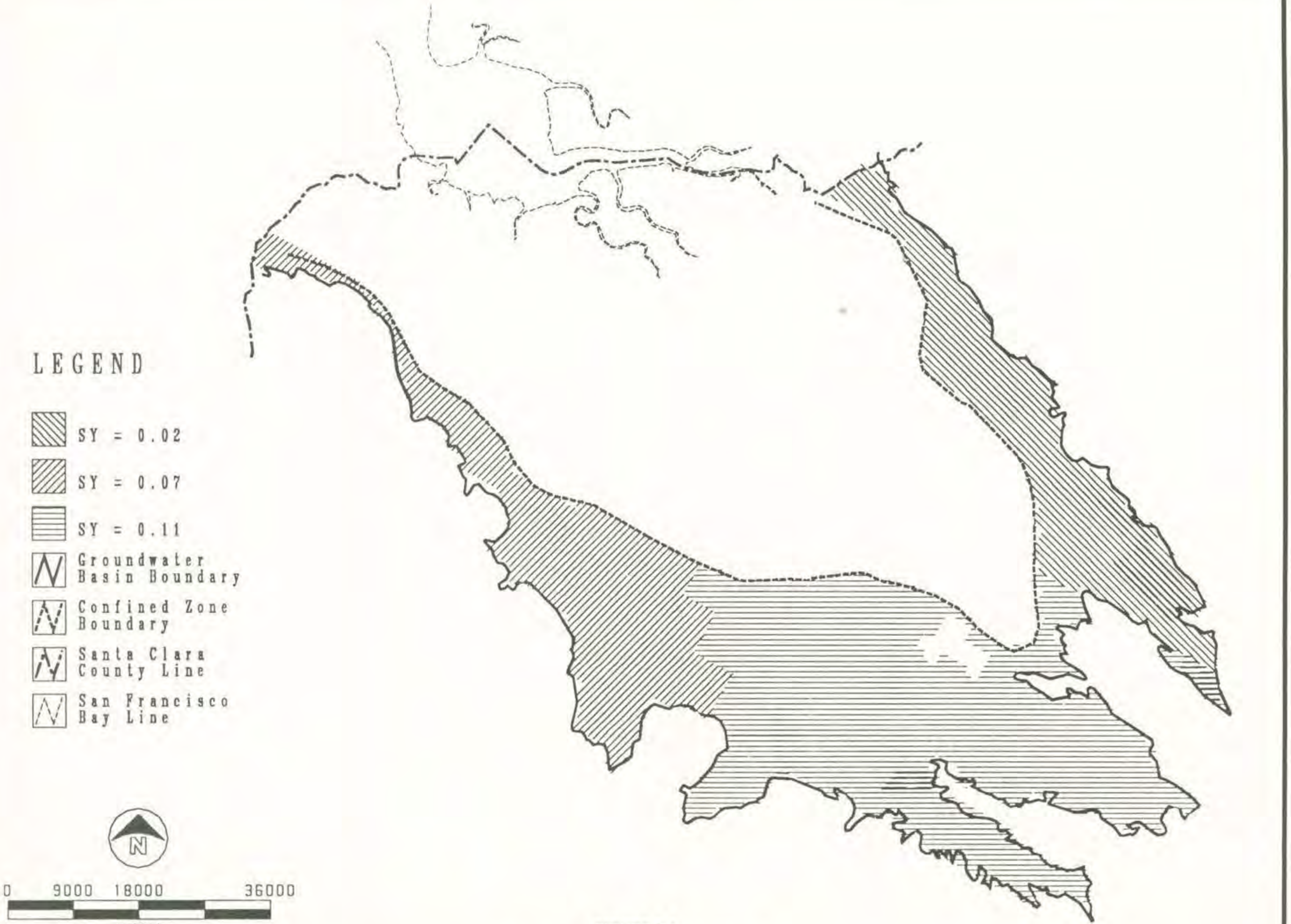


FIGURE 5-4
REVISED SPECIFIC YIELD ZONES

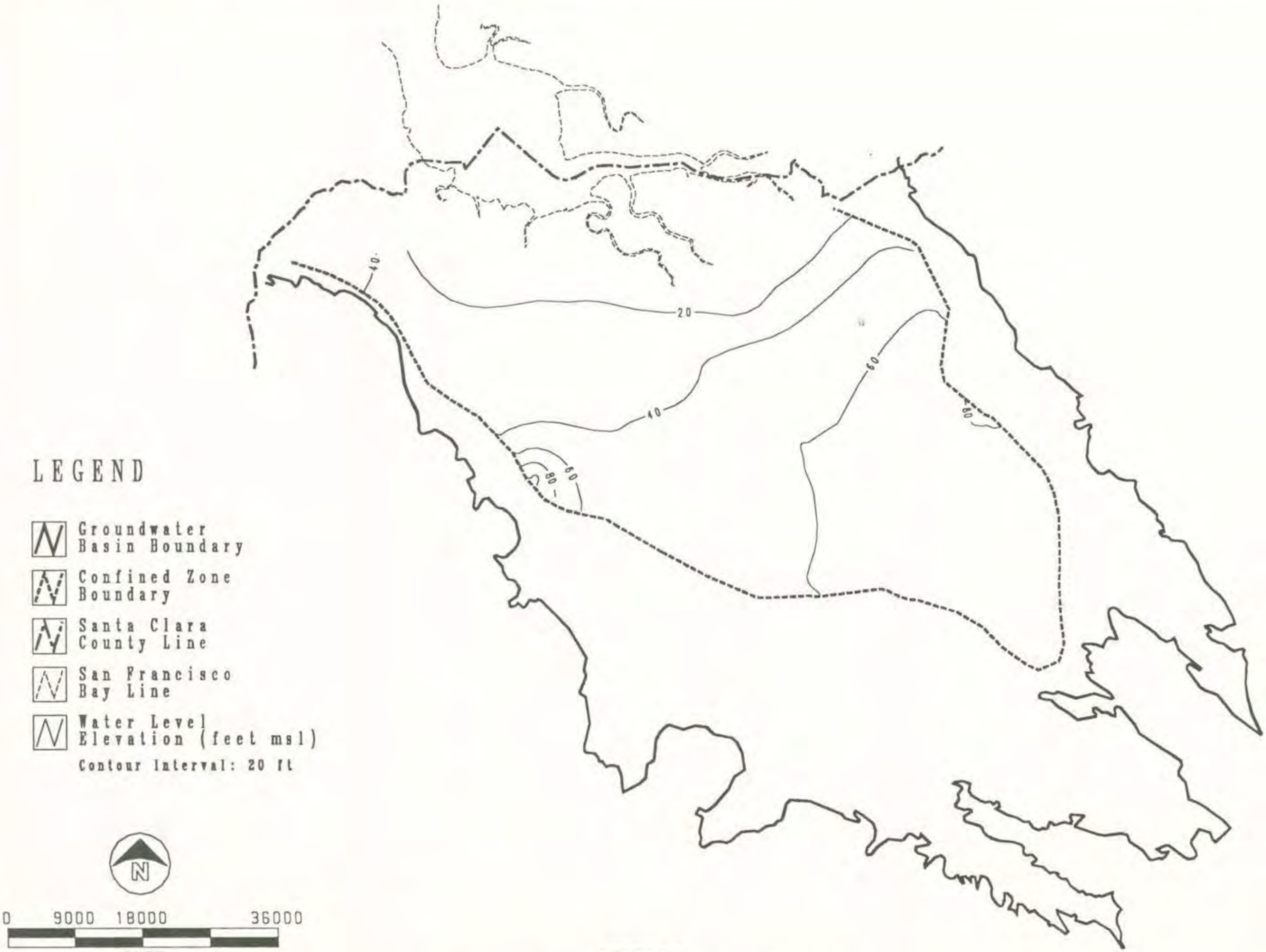


FIGURE 5-5
CALIBRATED STEADY STATE HEADS, MODEL LAYER 1

SSCONT1.PAL SFO27295.BM

October 12, 1992

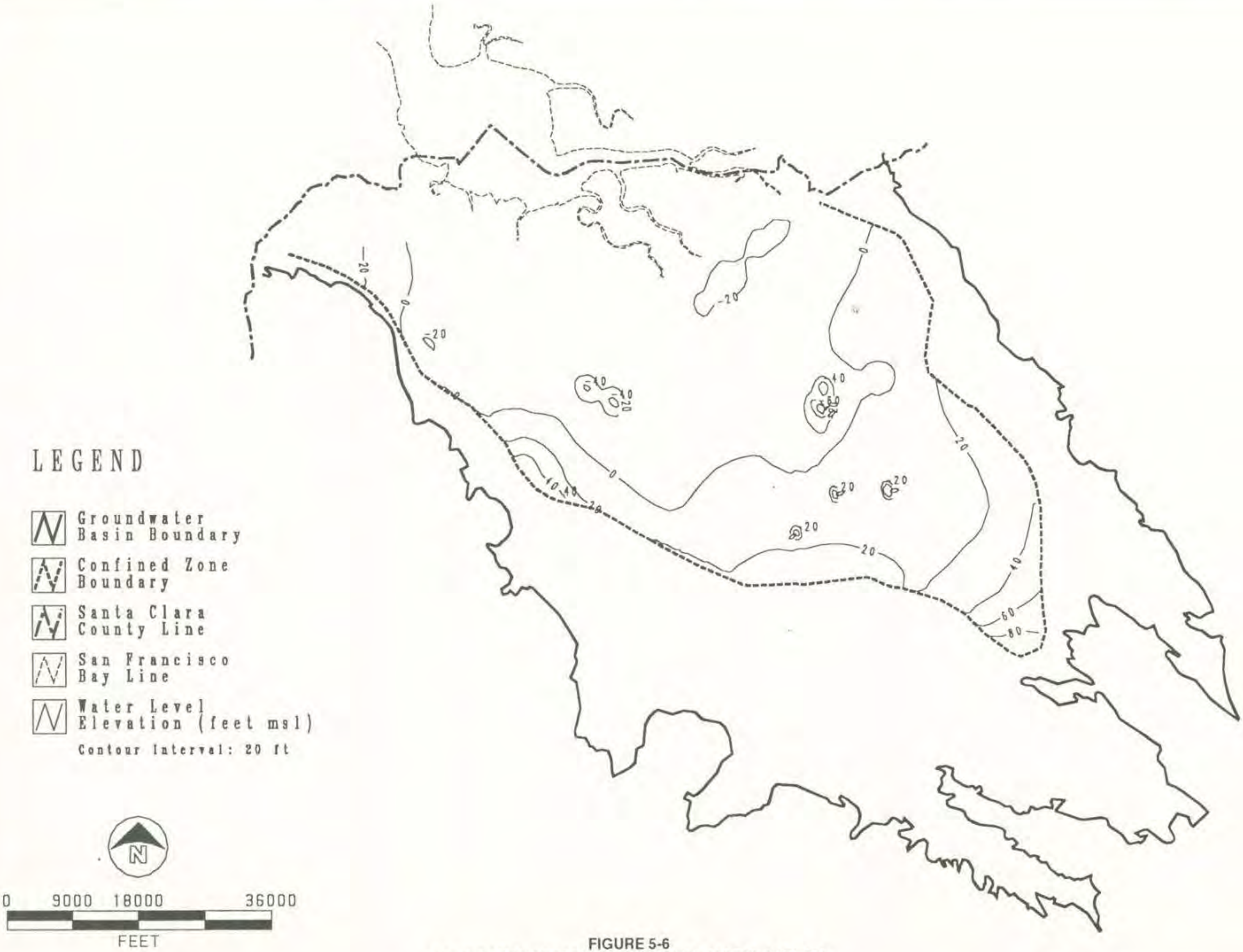


FIGURE 5-6
CALIBRATED STEADY STATE HEADS, MODEL LAYER 2

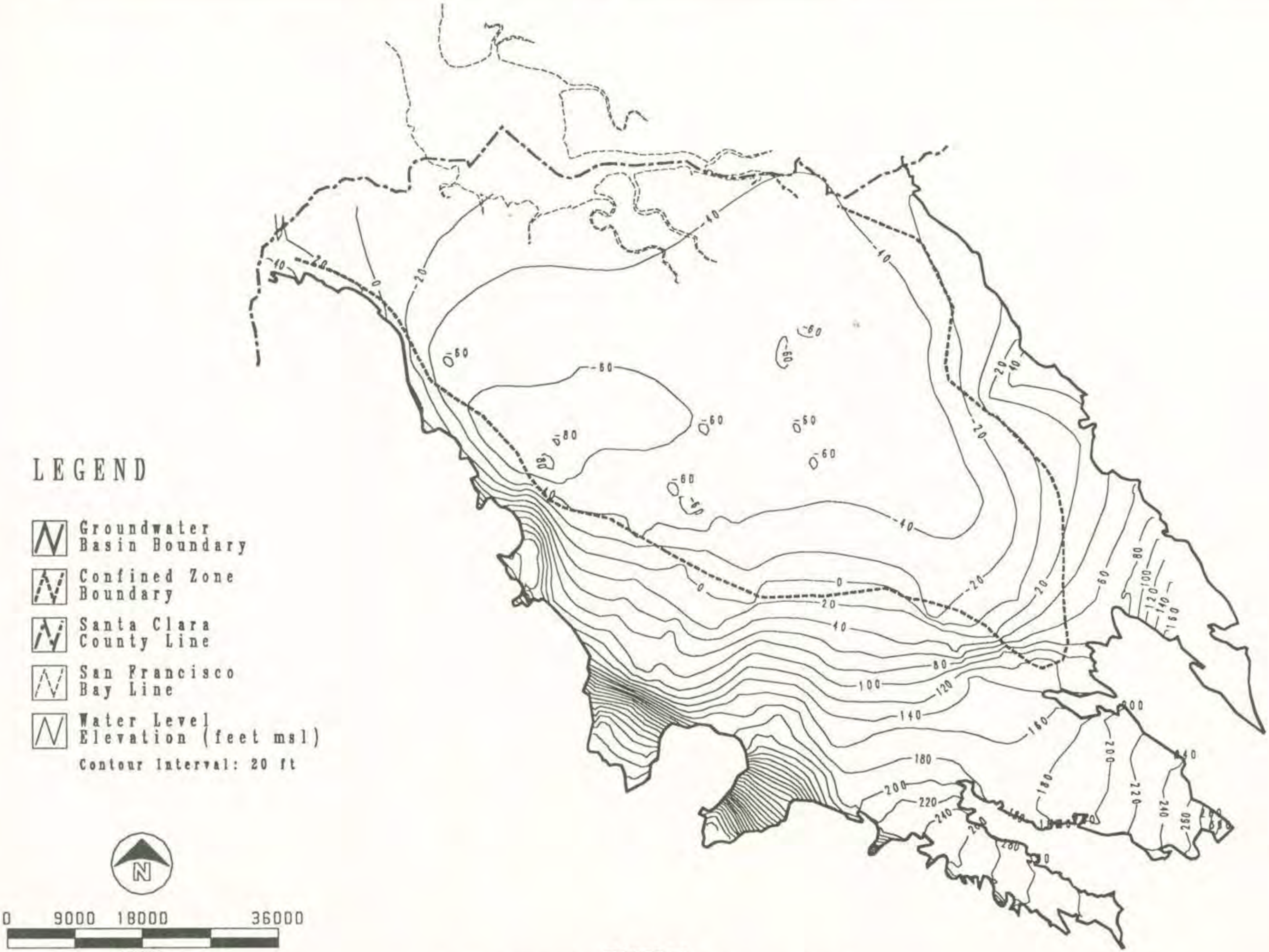


FIGURE 5-7
CALIBRATED STEADY STATE HEADS, MODEL LAYER 3

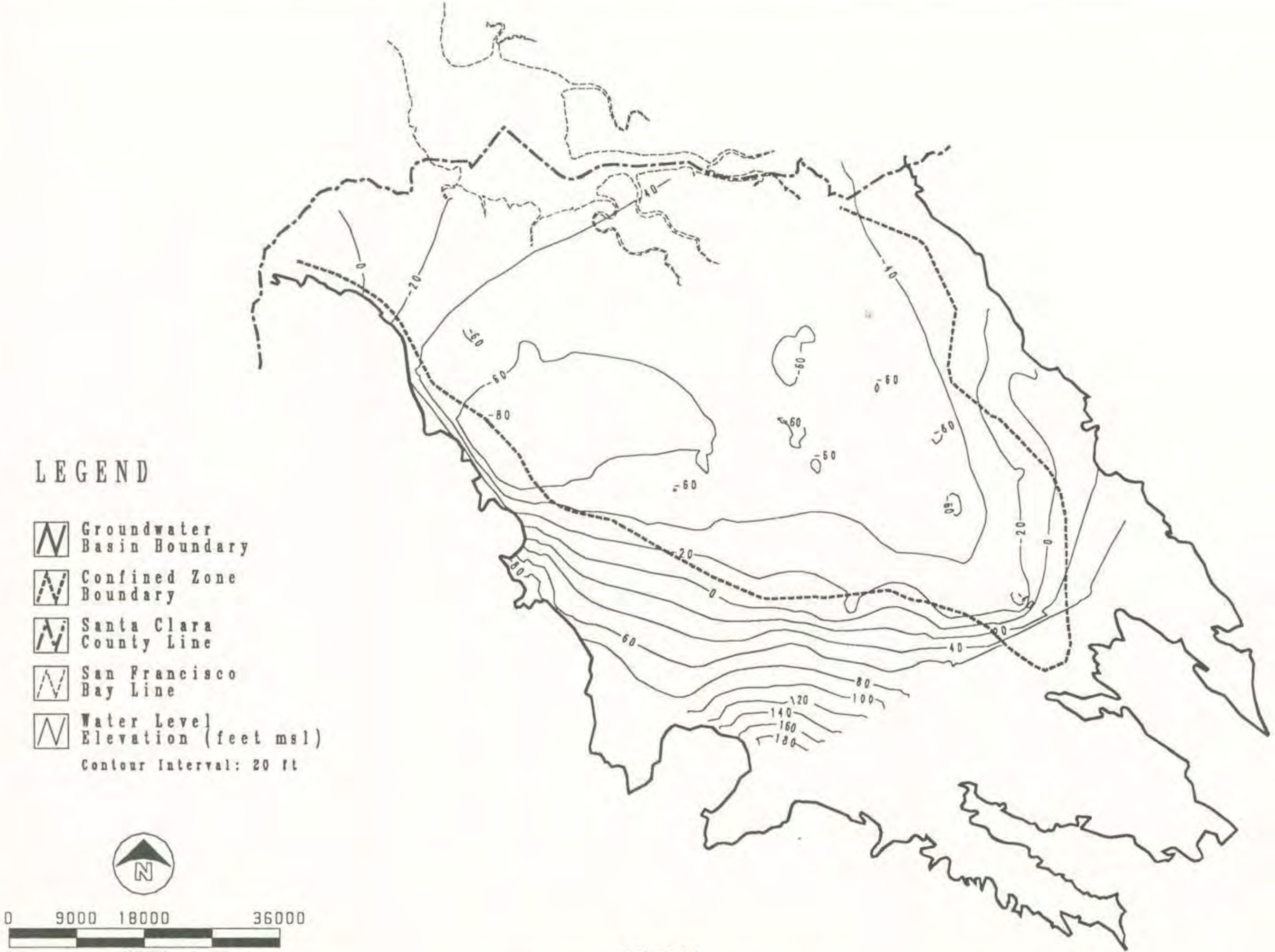


FIGURE 5-8
CALIBRATED STEADY STATE HEADS, MODEL LAYER 4

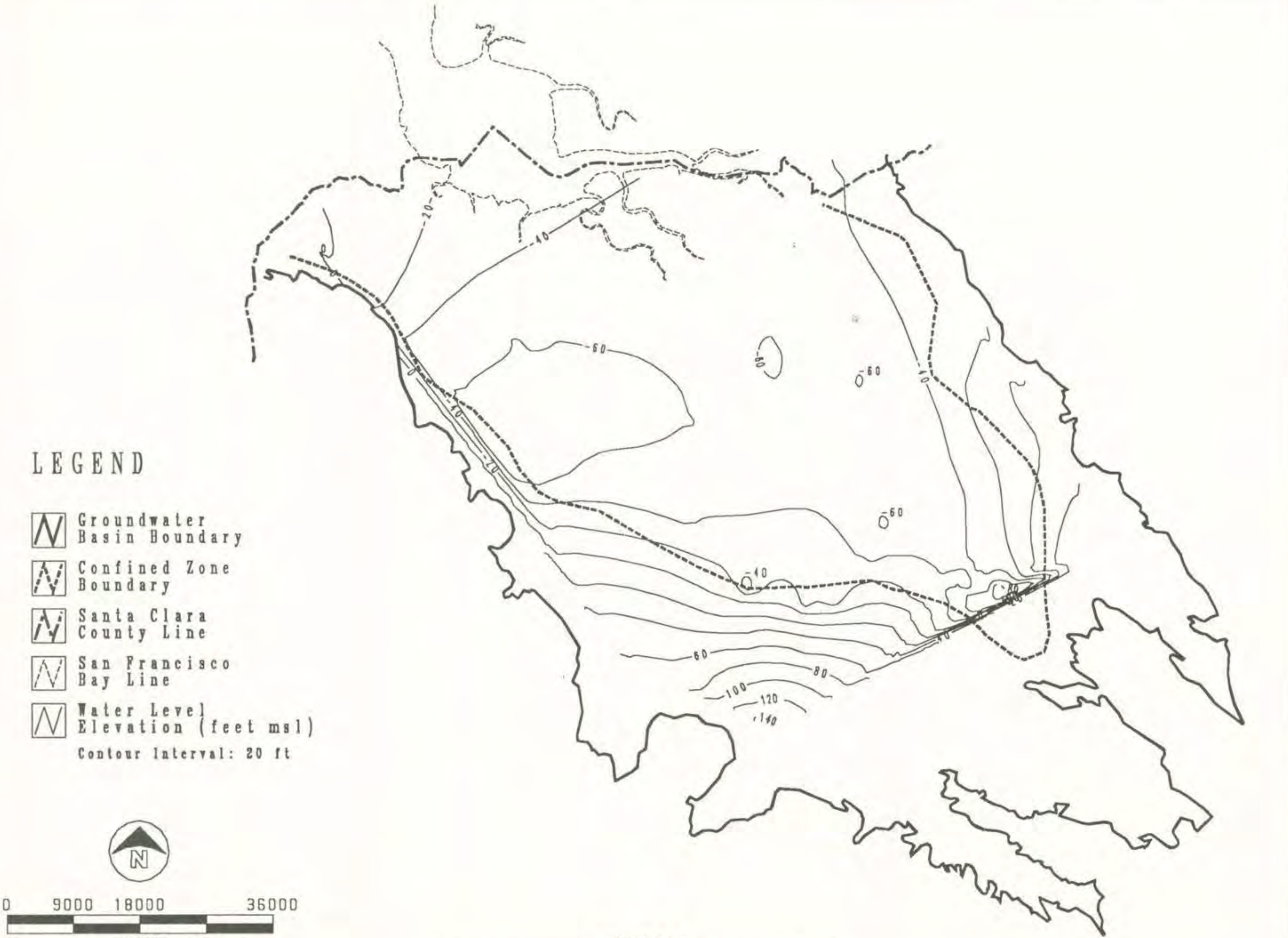


FIGURE 5-9
CALIBRATED STEADY STATE HEADS, MODEL LAYER 5

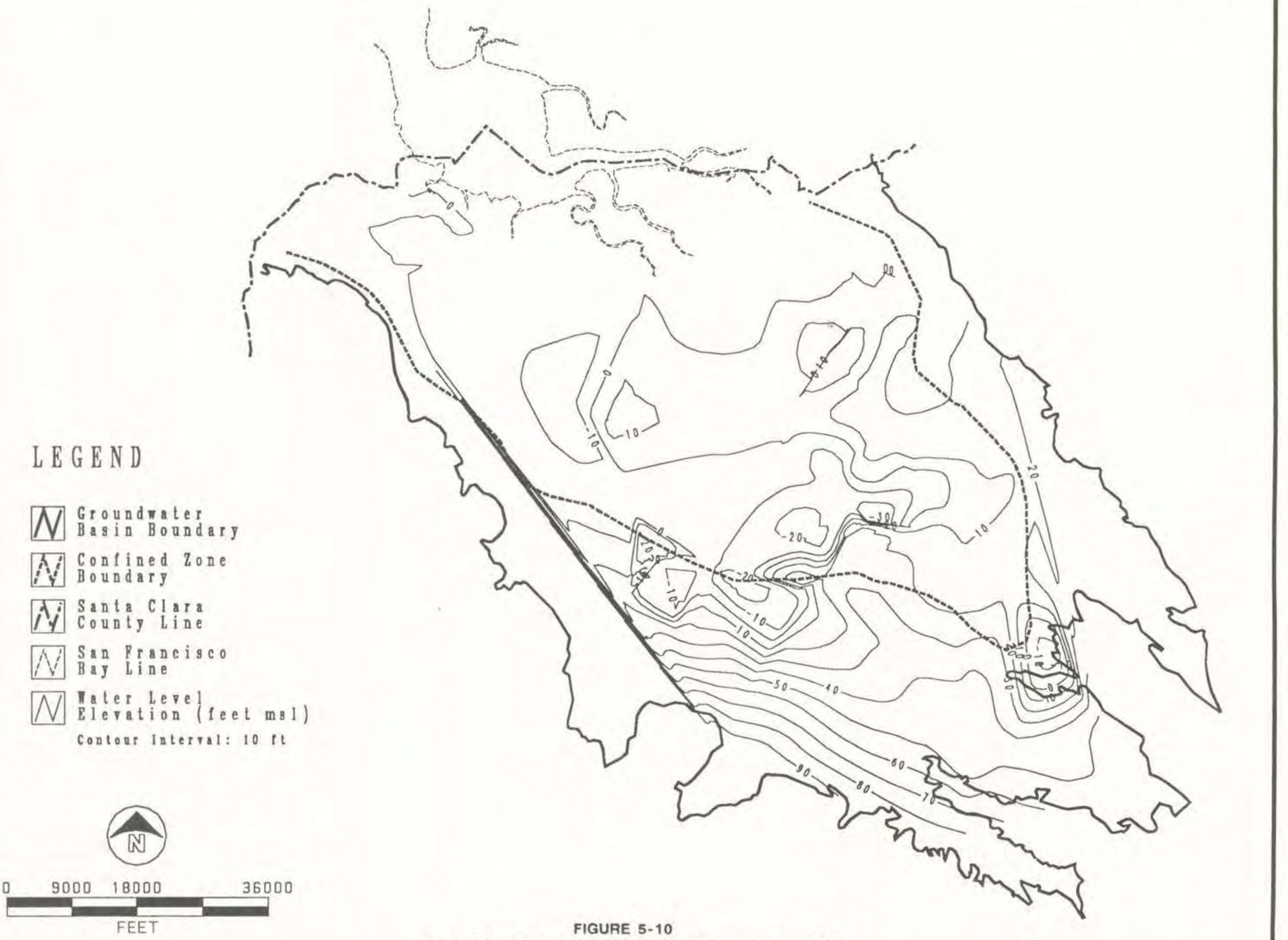


FIGURE 5-10
COMPOSITE HEAD MAP-STEADY STATE SIMULATION

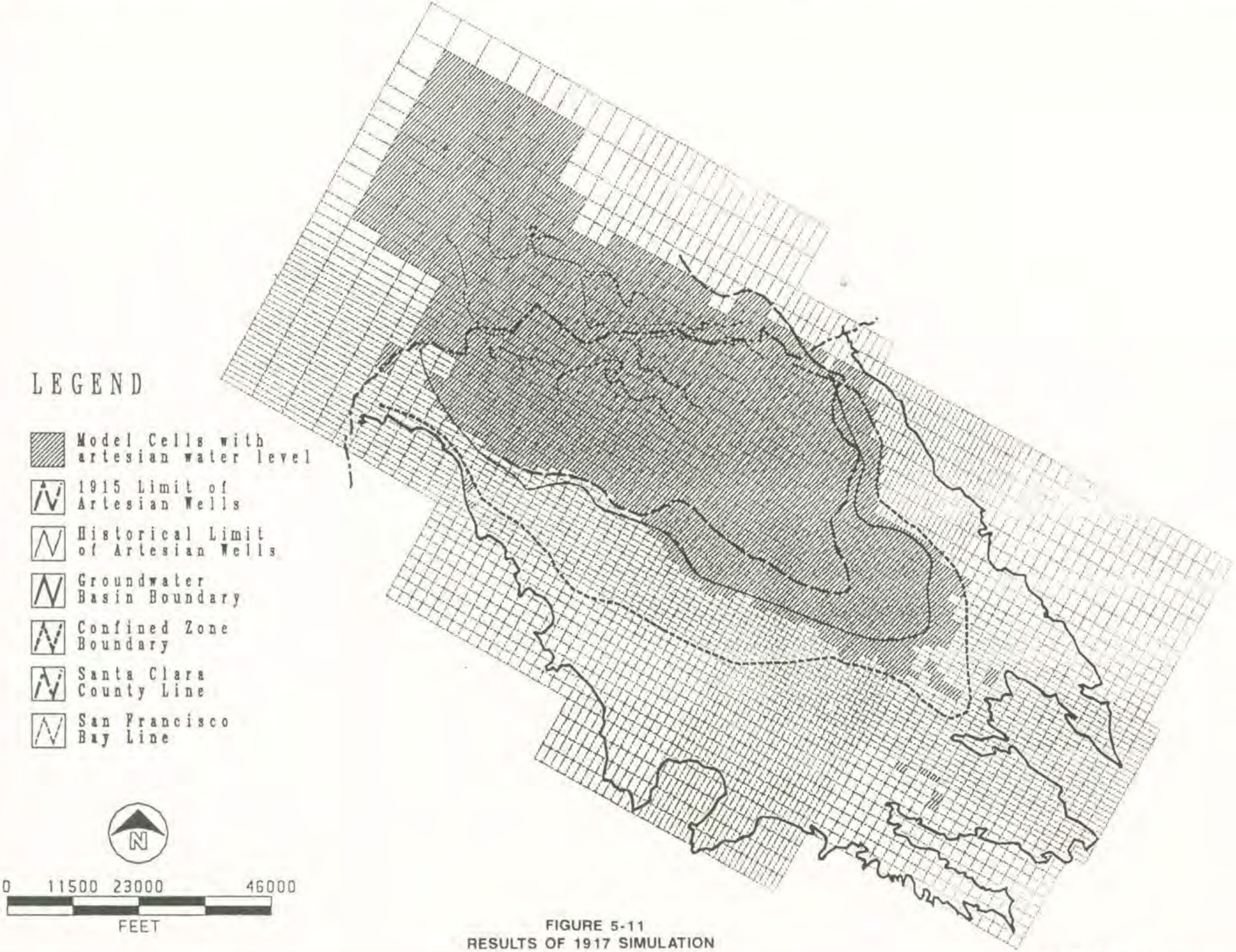

LEGEND
Model Cells with artesian water level
1915 Limit of Artesian Wells
Historical Limit of Artesian Wells
Groundwater Basin Boundary
Confined Zone Boundary
Santa Clara County Line
San Francisco Bay Line
N
0 11500 23000 46000
FEET

FIGURE 5-11
RESULTS OF 1917 SIMULATION

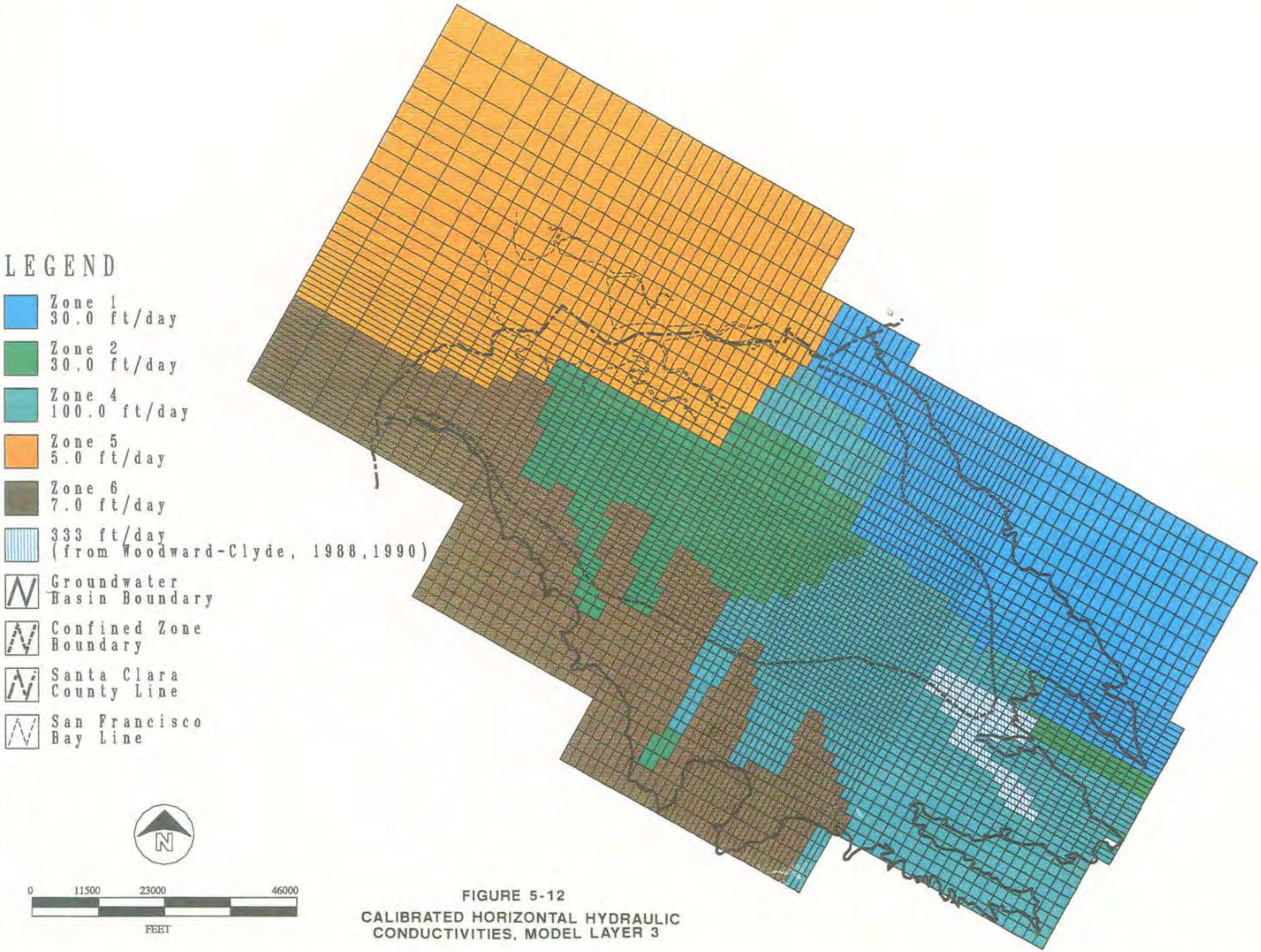


FIGURE 5-12

CALIBRATED HORIZONTAL HYDRAULIC CONDUCTIVITIES, MODEL LAYER 3

CH2M HILL

CSB3.AML

December 09, 1992

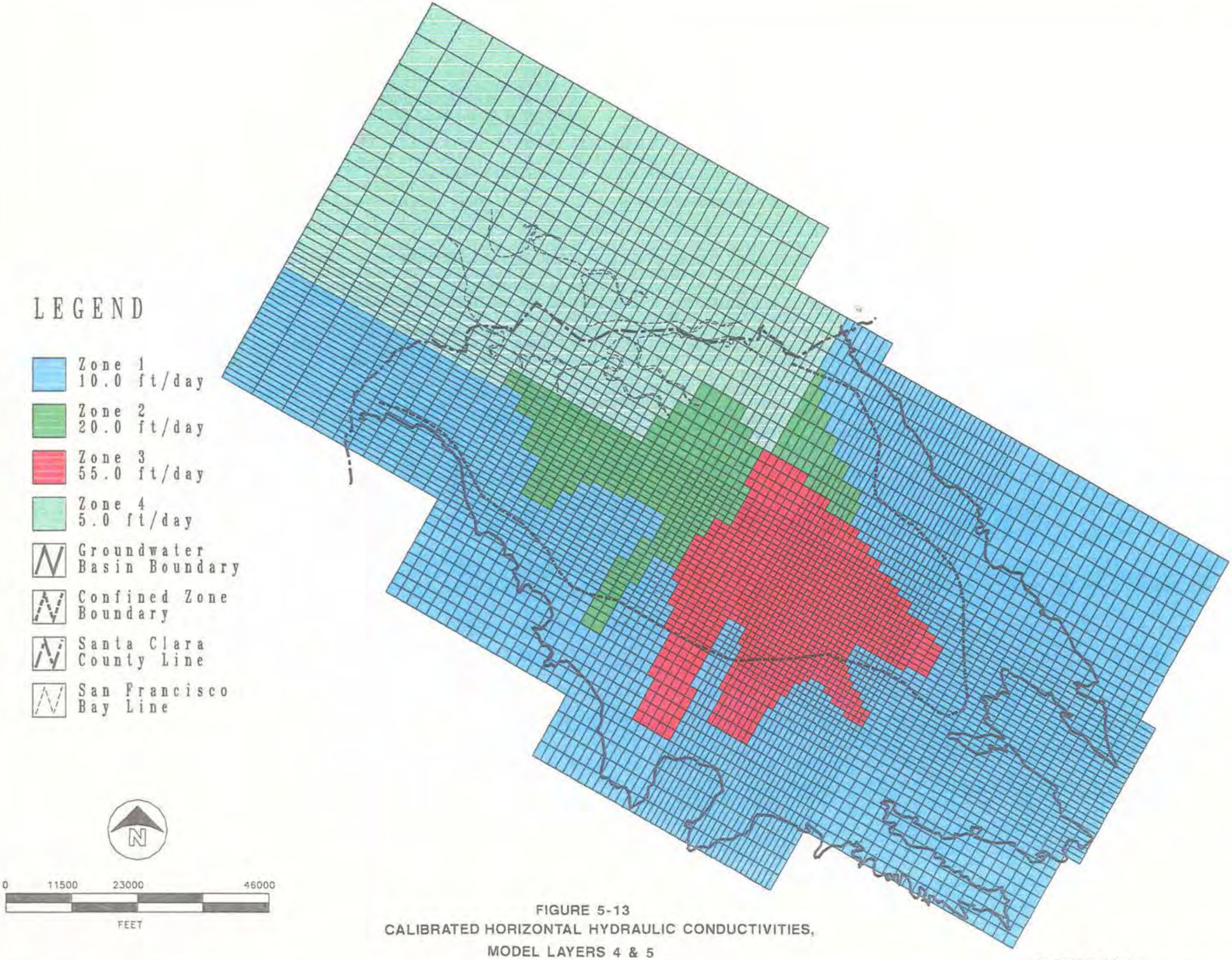


FIGURE 5-13
CALIBRATED HORIZONTAL HYDRAULIC CONDUCTIVITIES,
MODEL LAYERS 4 & 5

CH2M HILL

SFO27295.BM

October 13, 1992

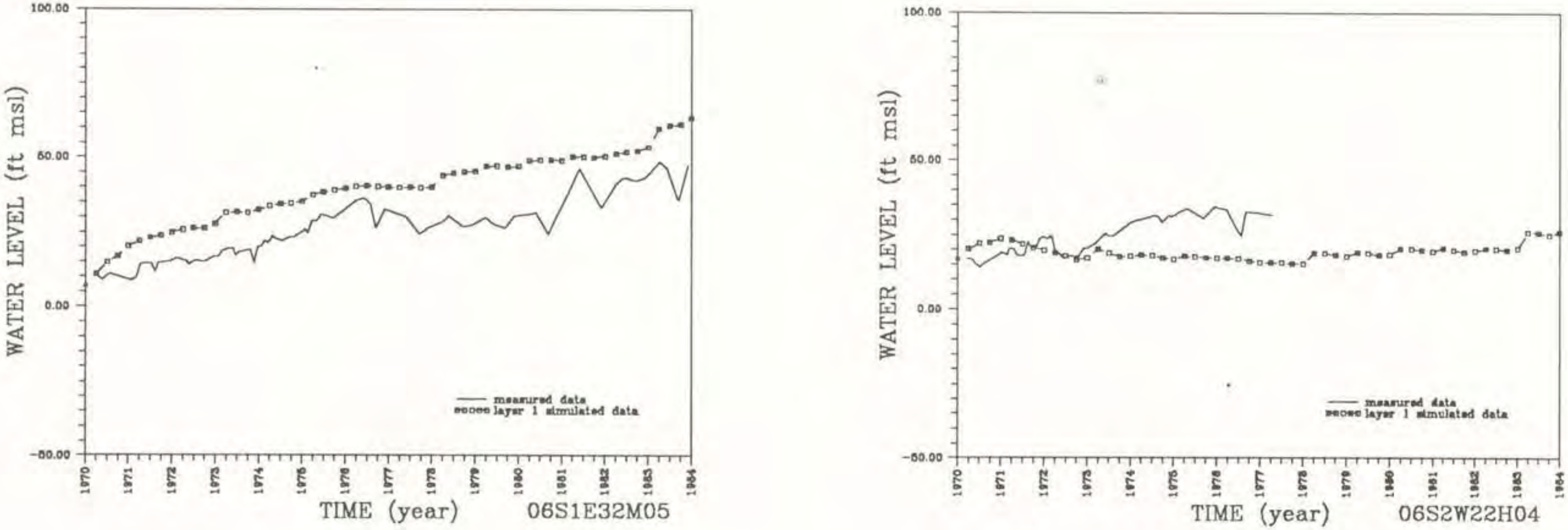


FIGURE 5-14
CALIBRATED HYDROGRAPHS, MODEL LAYER 1

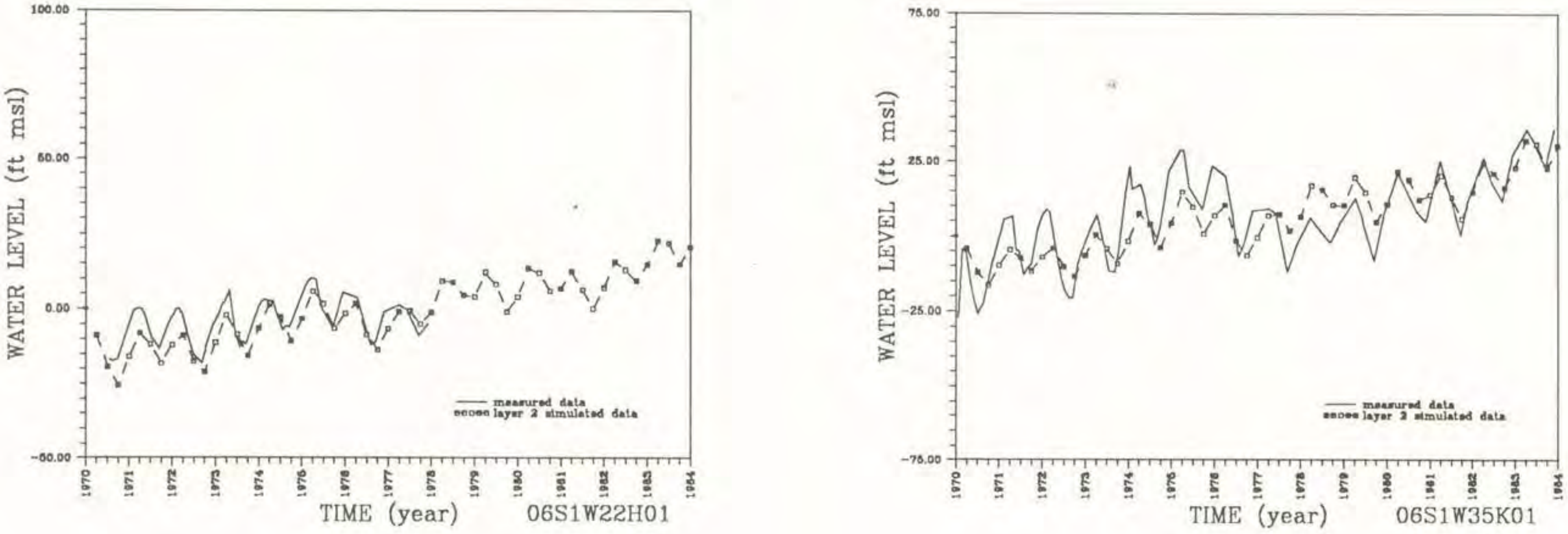


FIGURE 5-15
CALIBRATED HYDROGRAPHS, MODEL LAYER 2

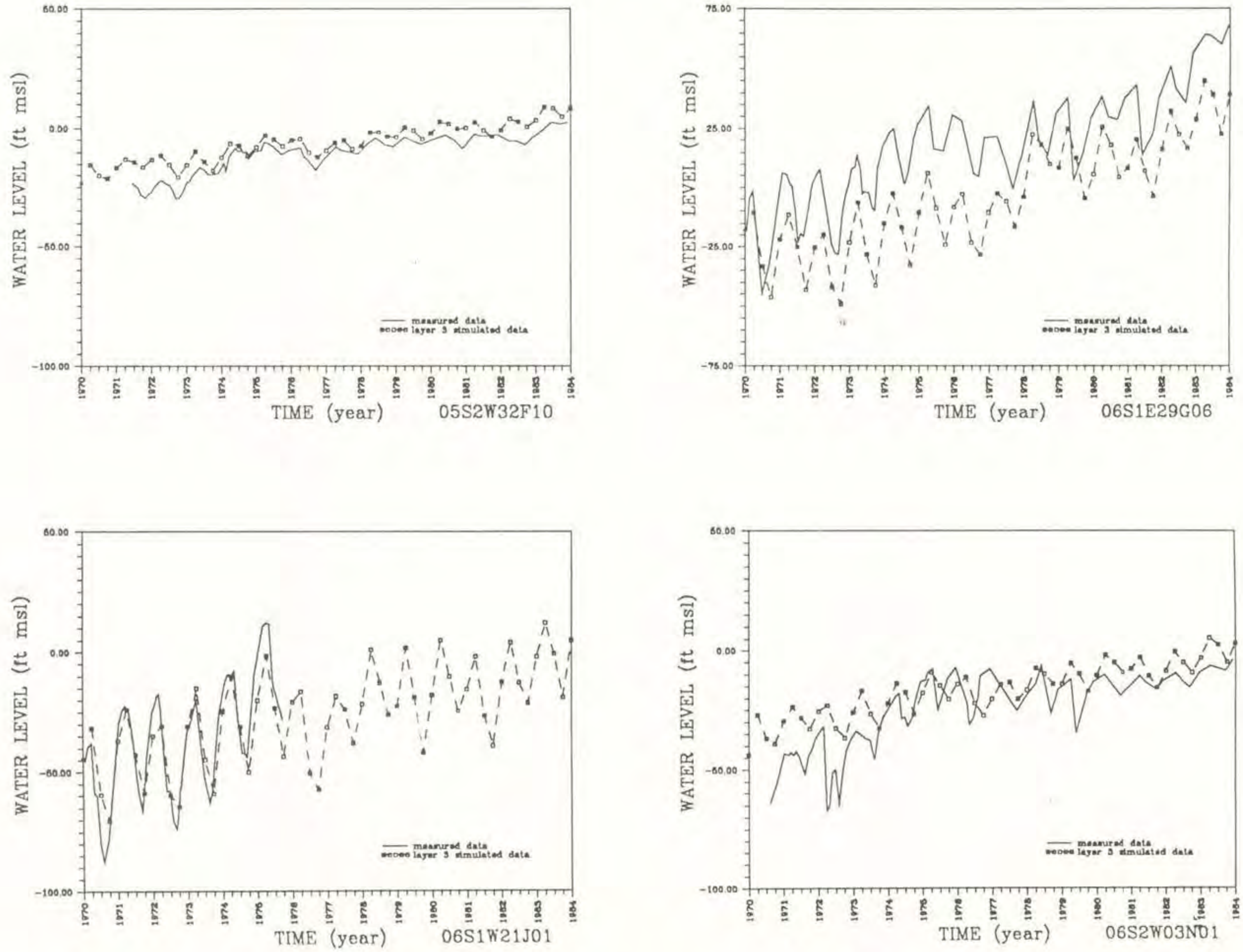


FIGURE 5-16a
CALIBRATED HYDROGRAPHS, MODEL LAYER 3

HGRAPH3.AML SFO27295.BM

September 18, 1992

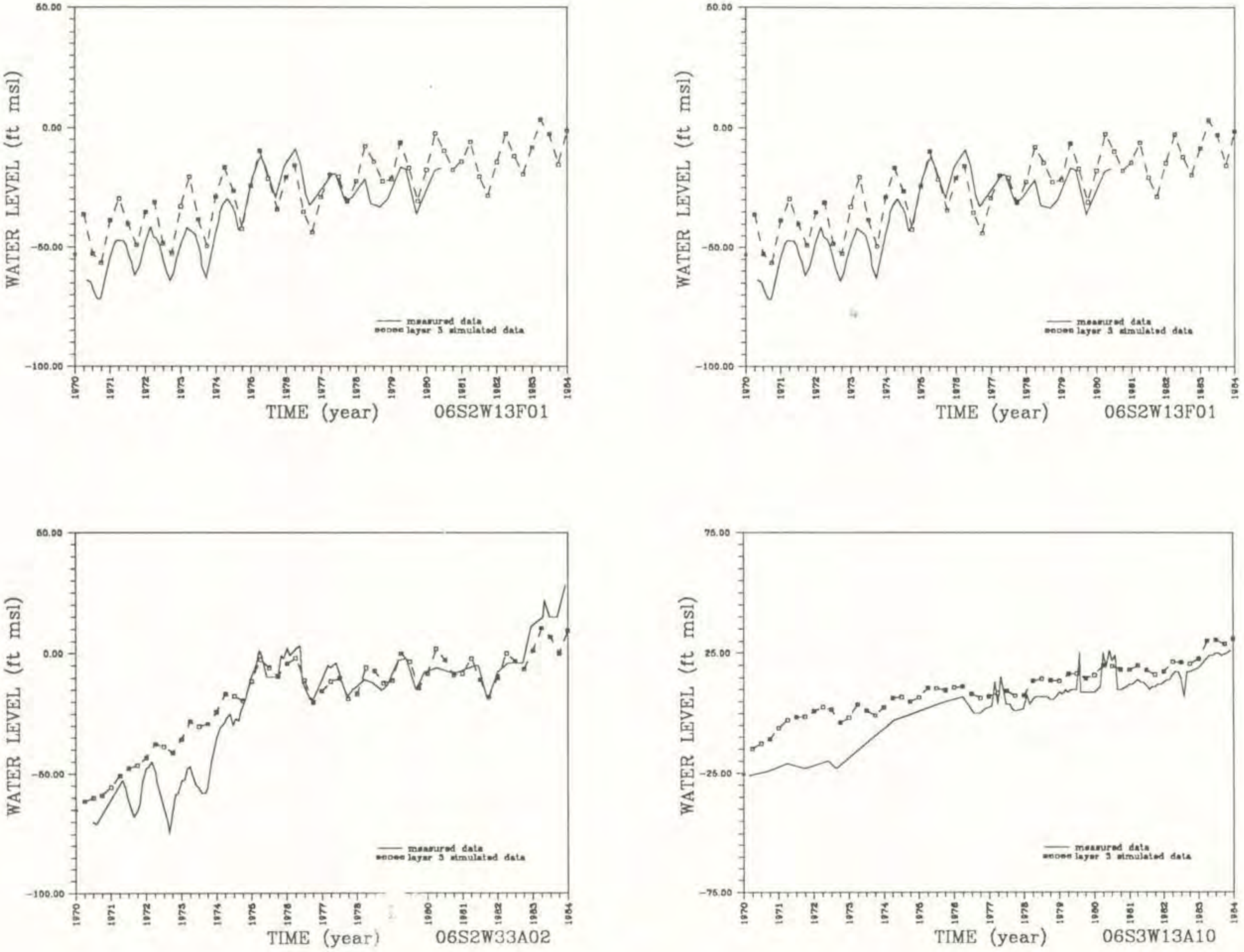


FIGURE 5-16b
CALIBRATED HYDROGRAPHS, MODEL LAYER 3

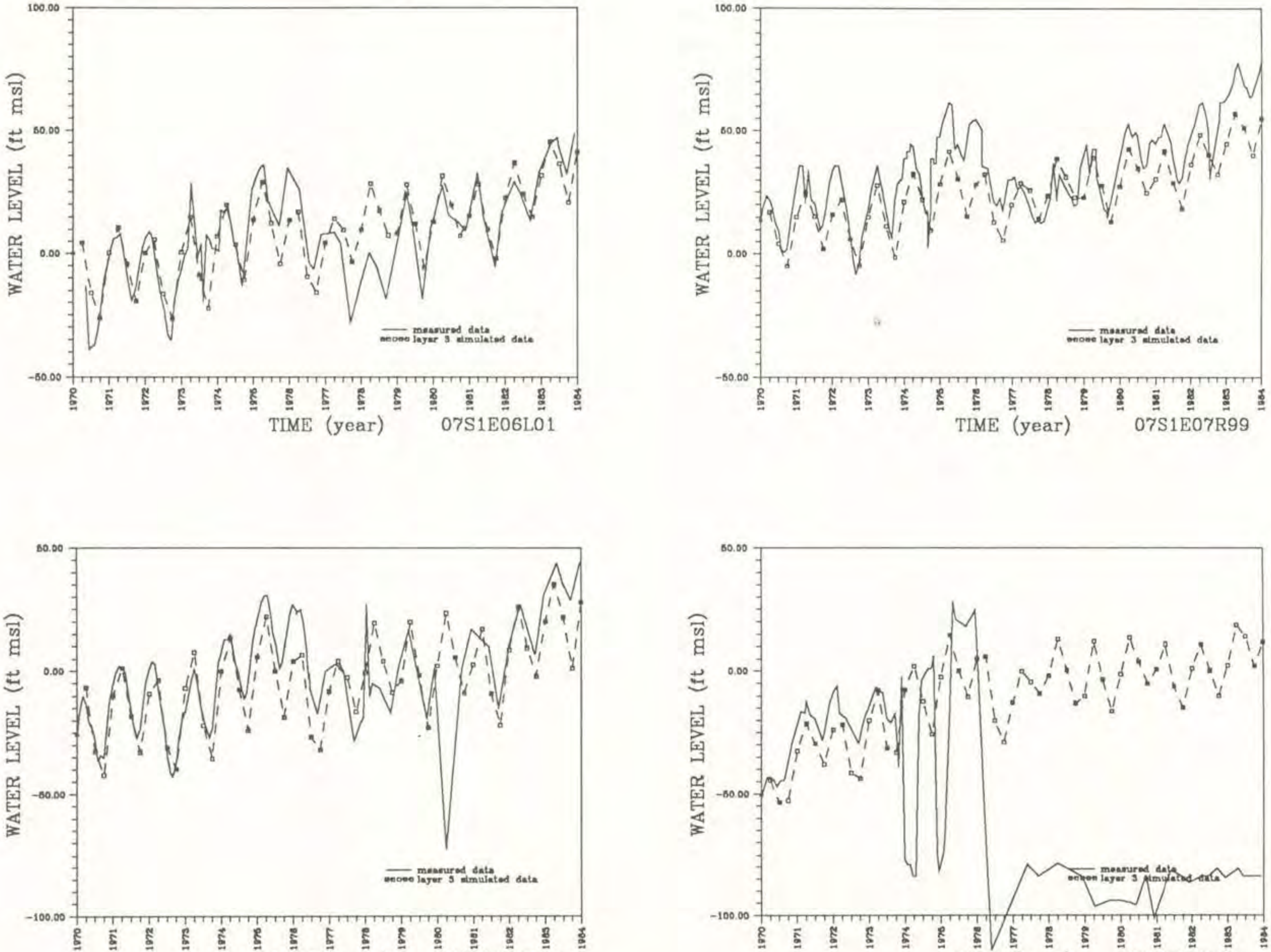


FIGURE 5-16c
CALIBRATED HYDROGRAPHS, MODEL LAYER 3

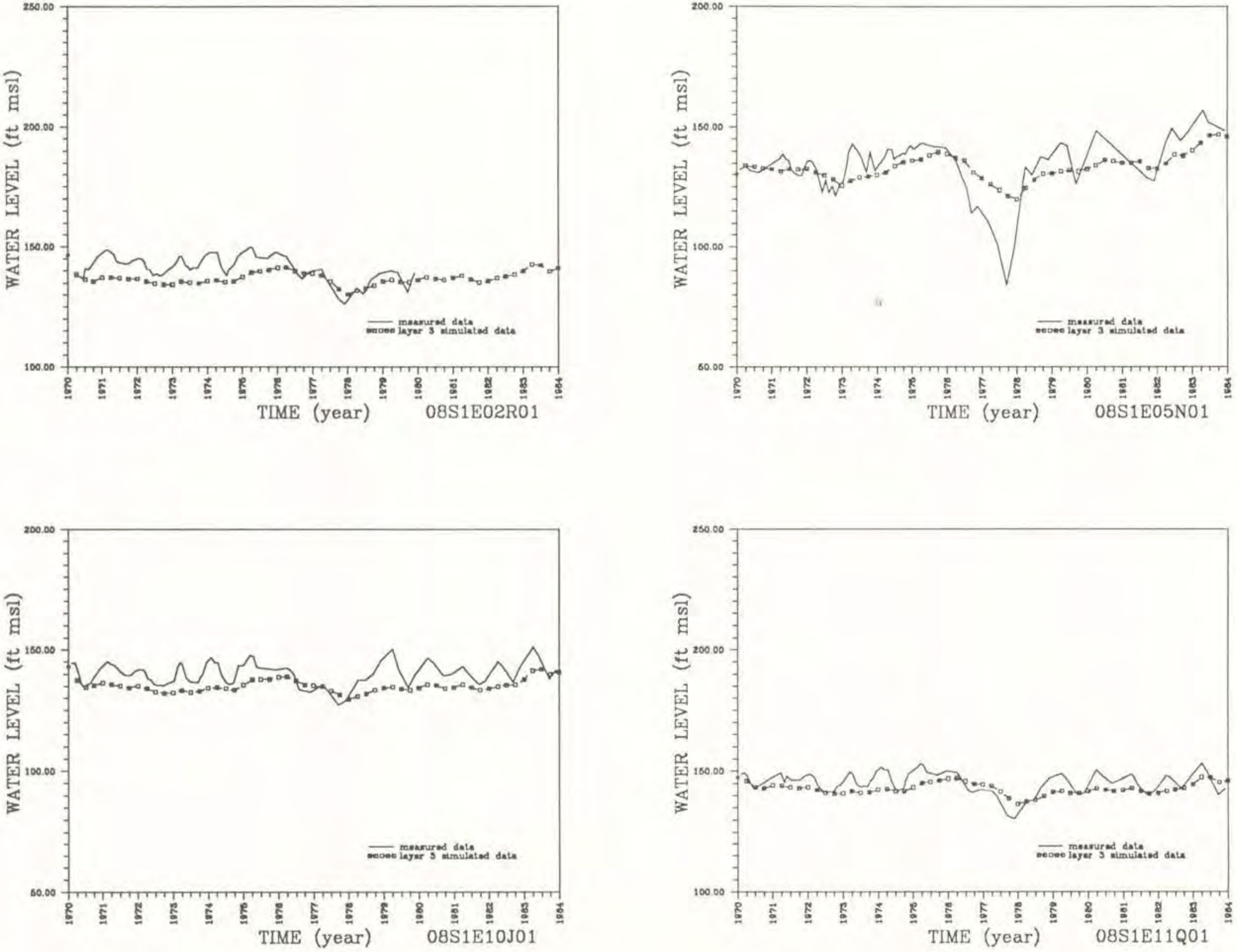


FIGURE 5-16d
CALIBRATED HYDROGRAPHS, MODEL LAYER 3

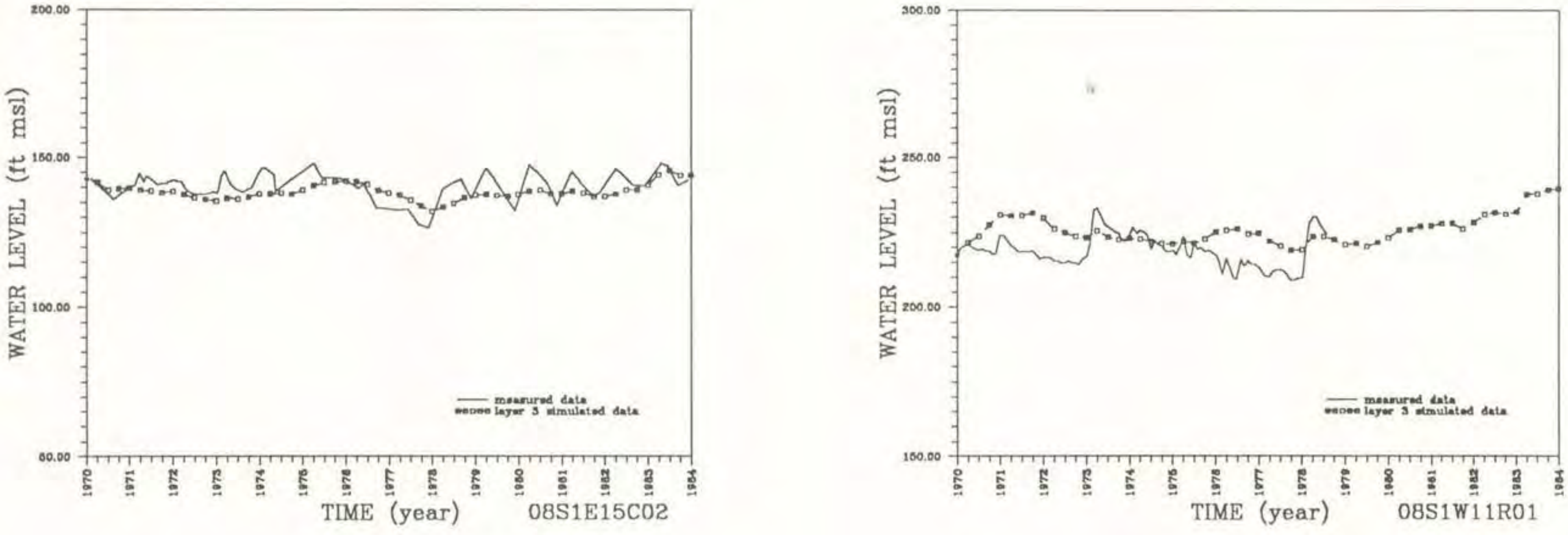


FIGURE 5-16e
CALIBRATED HYDROGRAPHS, MODEL LAYER 3

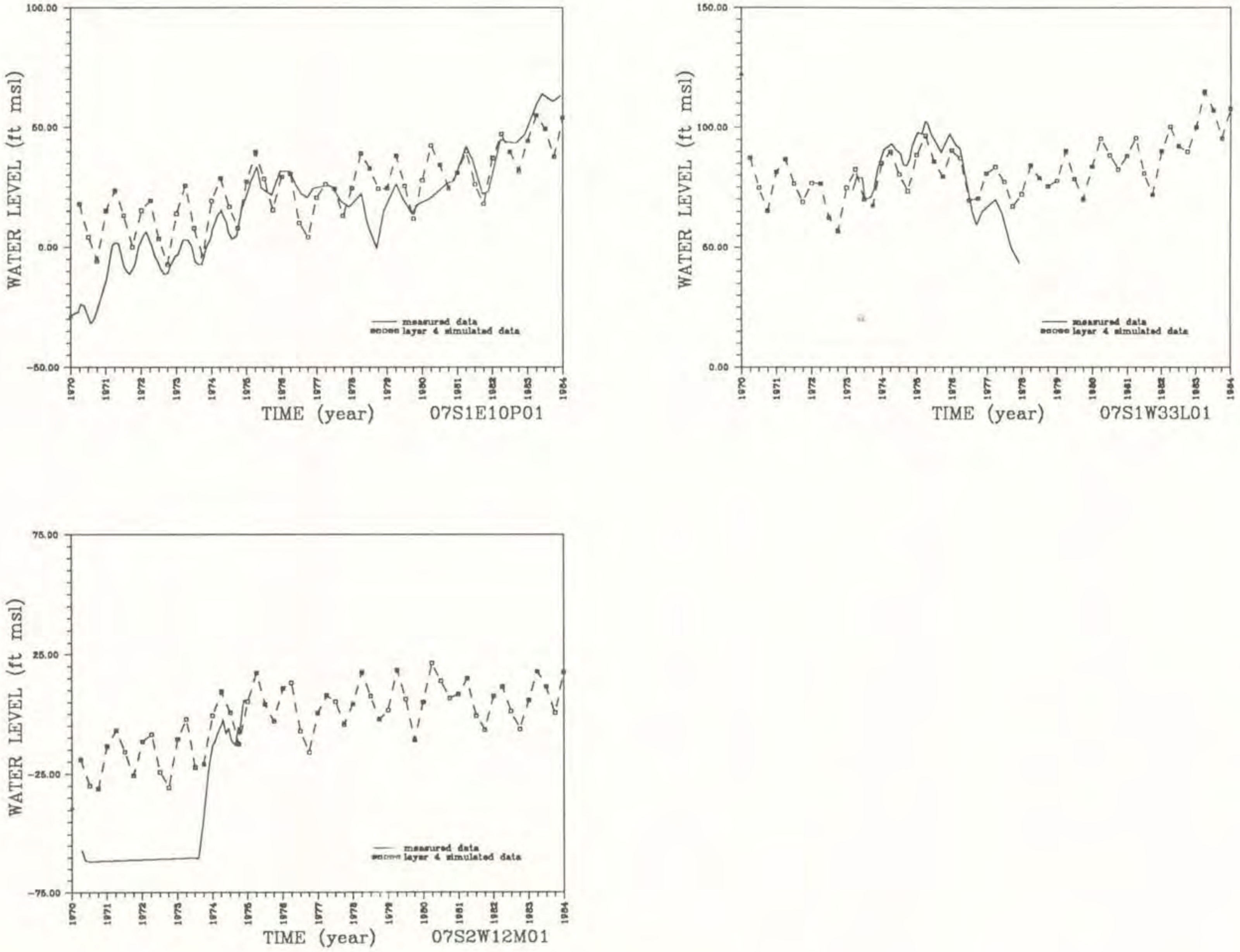


FIGURE 5-17
CALIBRATED HYDROGRAPHS, MODEL LAYER 4

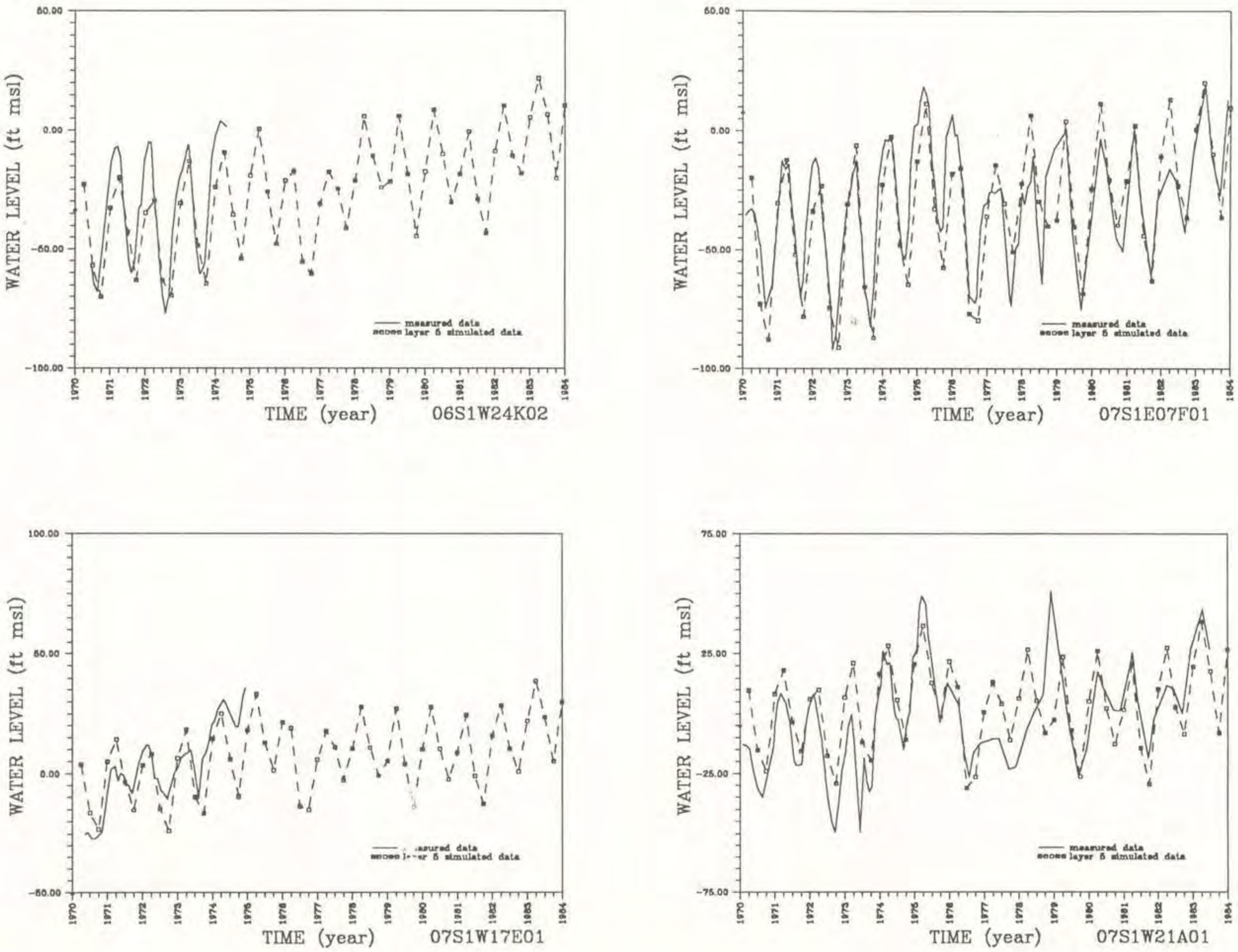


FIGURE 5-18
CALIBRATED HYDROGRAPHS, MODEL LAYER 5

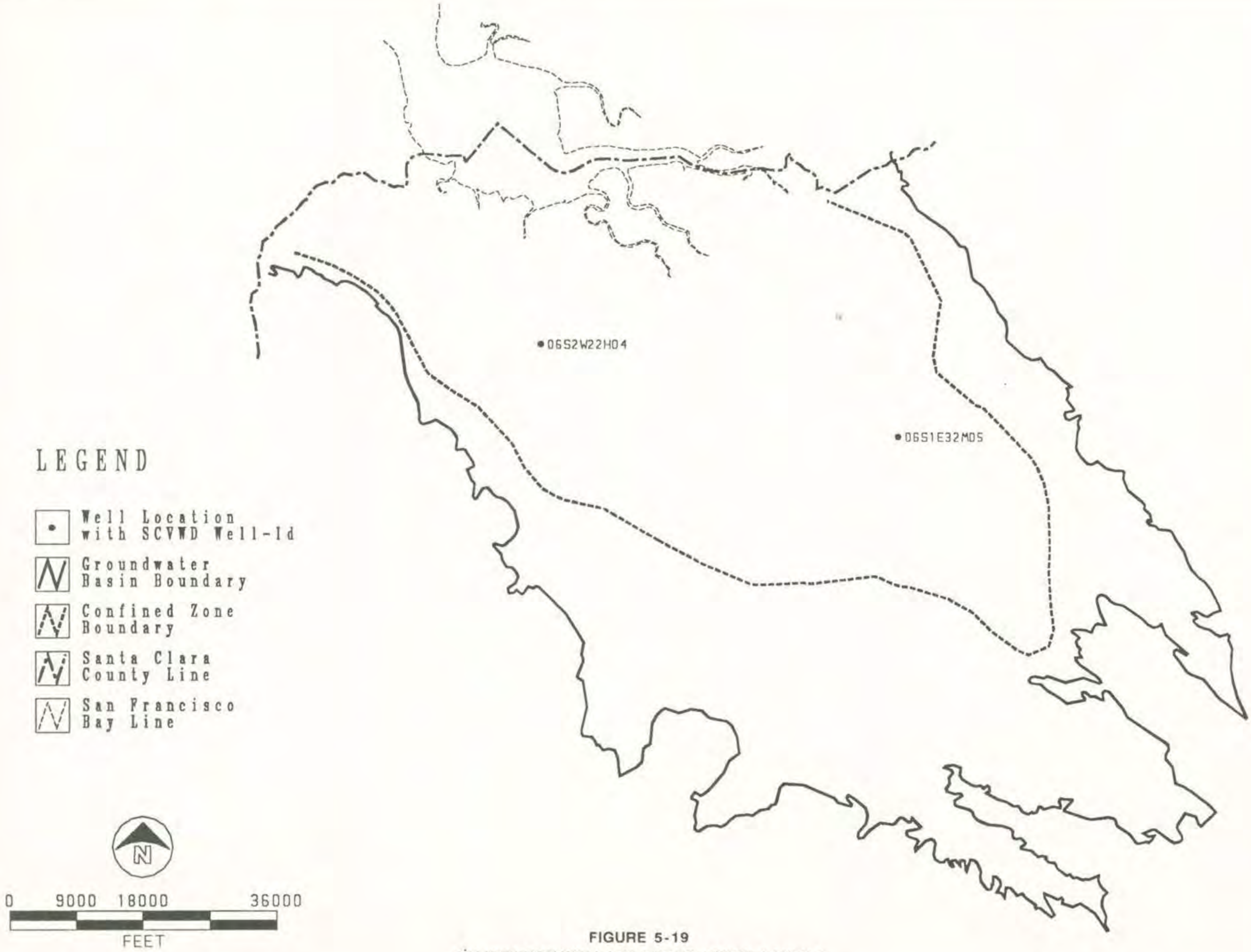


FIGURE 5-19
CALIBRATION WELL LOCATIONS, MODEL LAYER 1

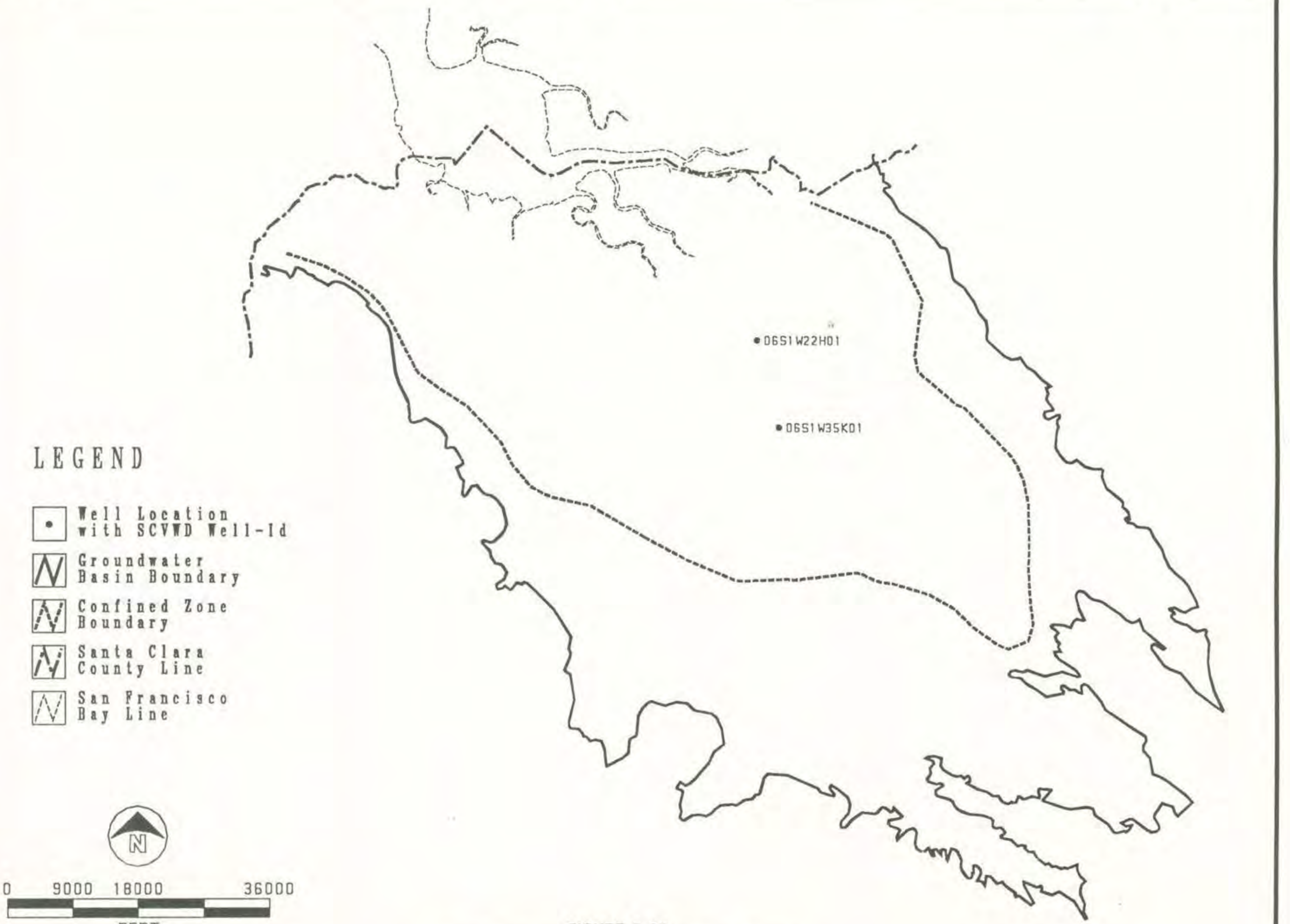


FIGURE 5-20
CALIBRATION WELL LOCATIONS, MODEL LAYER 2

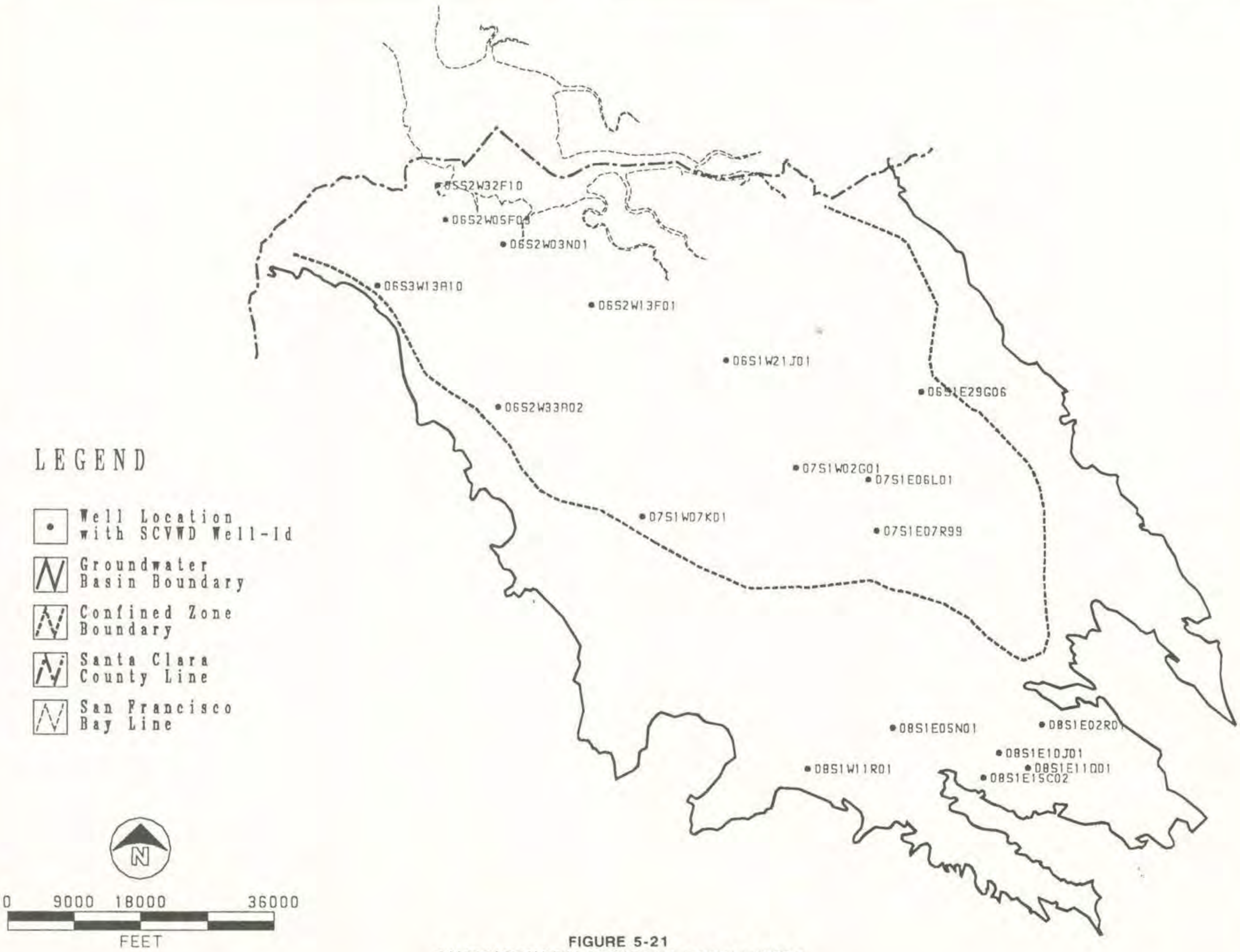


FIGURE 5-21
CALIBRATION WELL LOCATIONS, MODEL LAYER 3

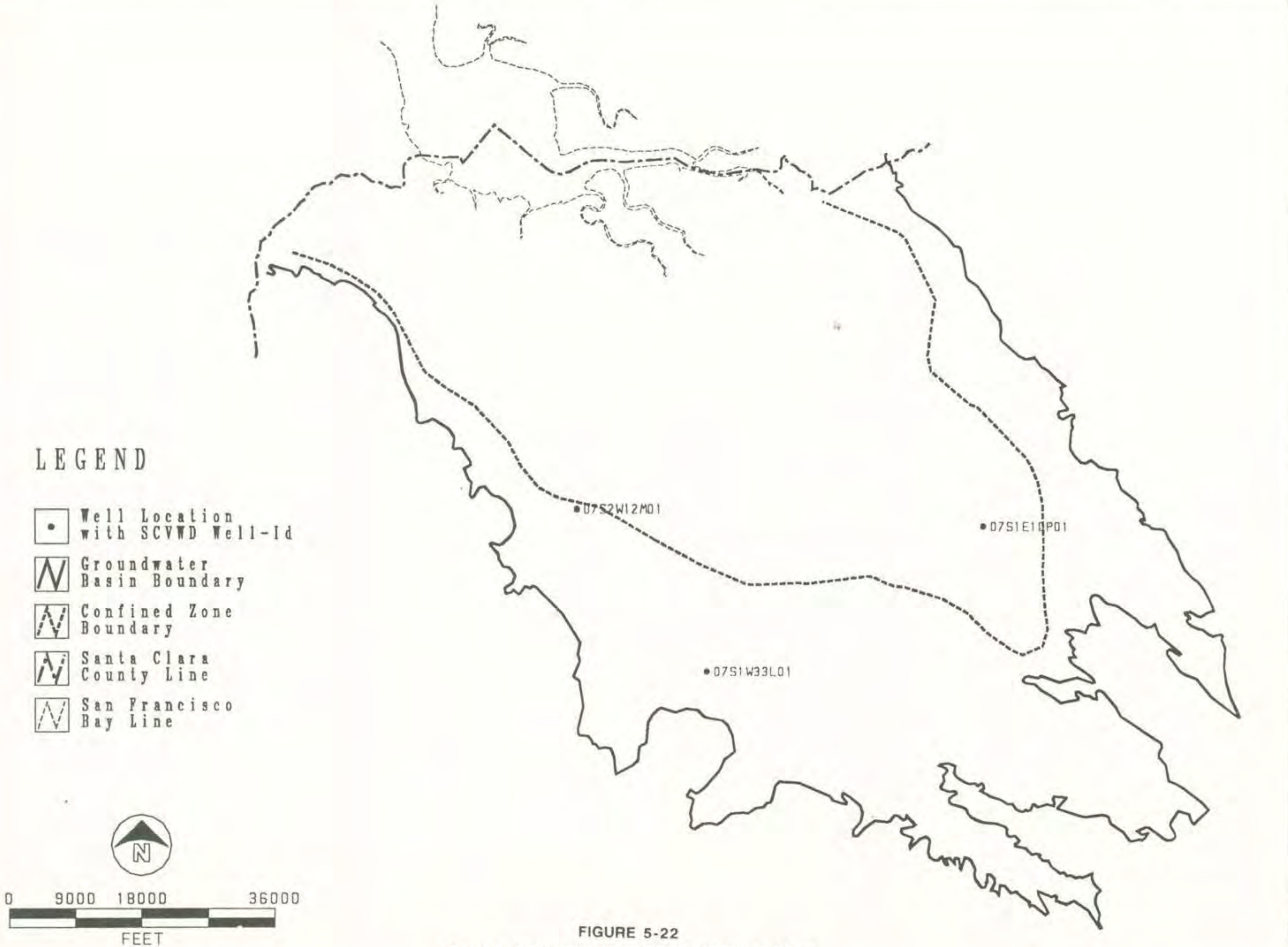


FIGURE 5-22

CALIBRATION WELL LOCATIONS, MODEL LAYER 4

CWELL.AML SFO27295.BM

CH2M HILL

October 14, 1992

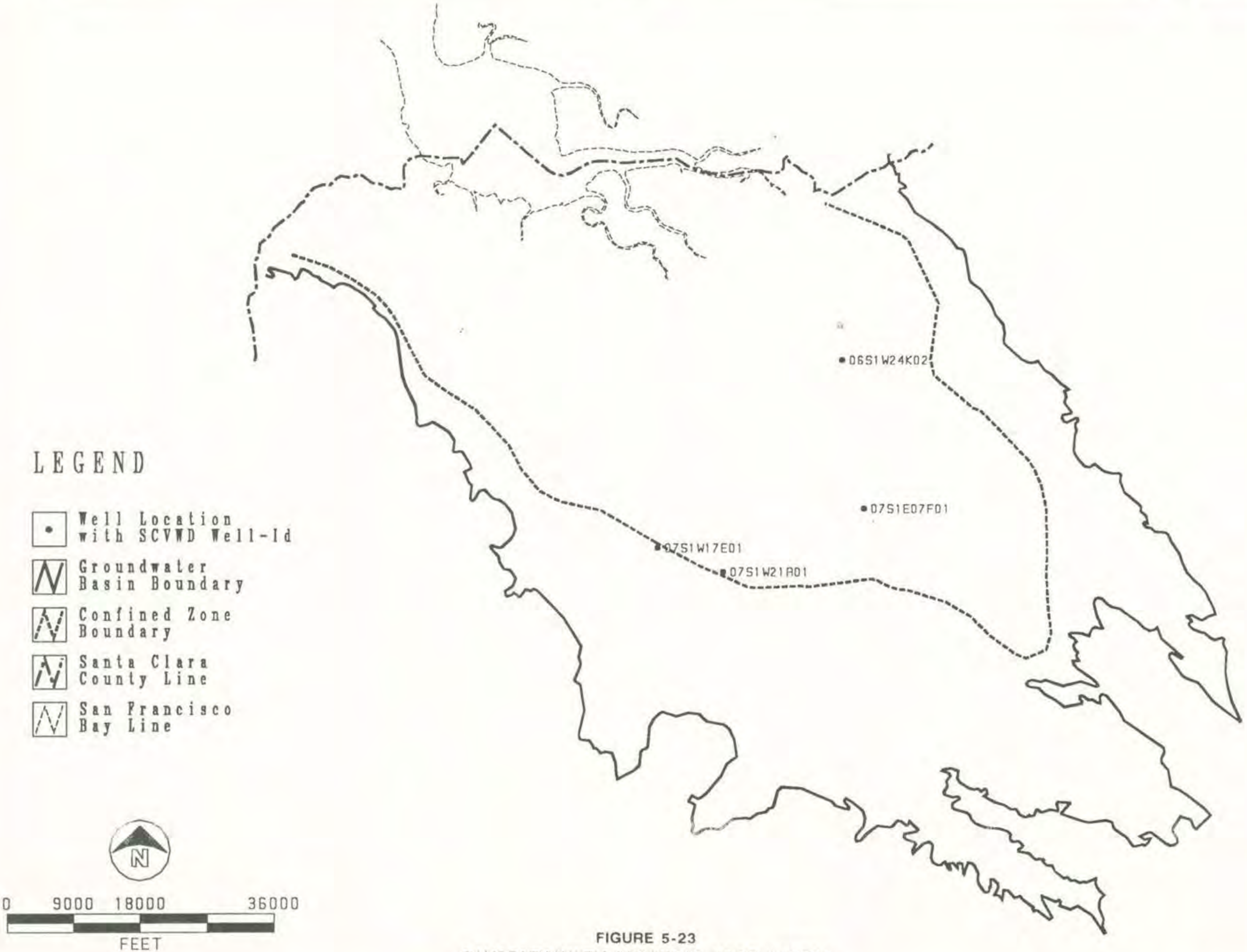


FIGURE 5-23
CALIBRATION WELL LOCATIONS, MODEL LAYER 5

CH2M HILL

CWELL.AML SFO27295.BM

October 14, 1992

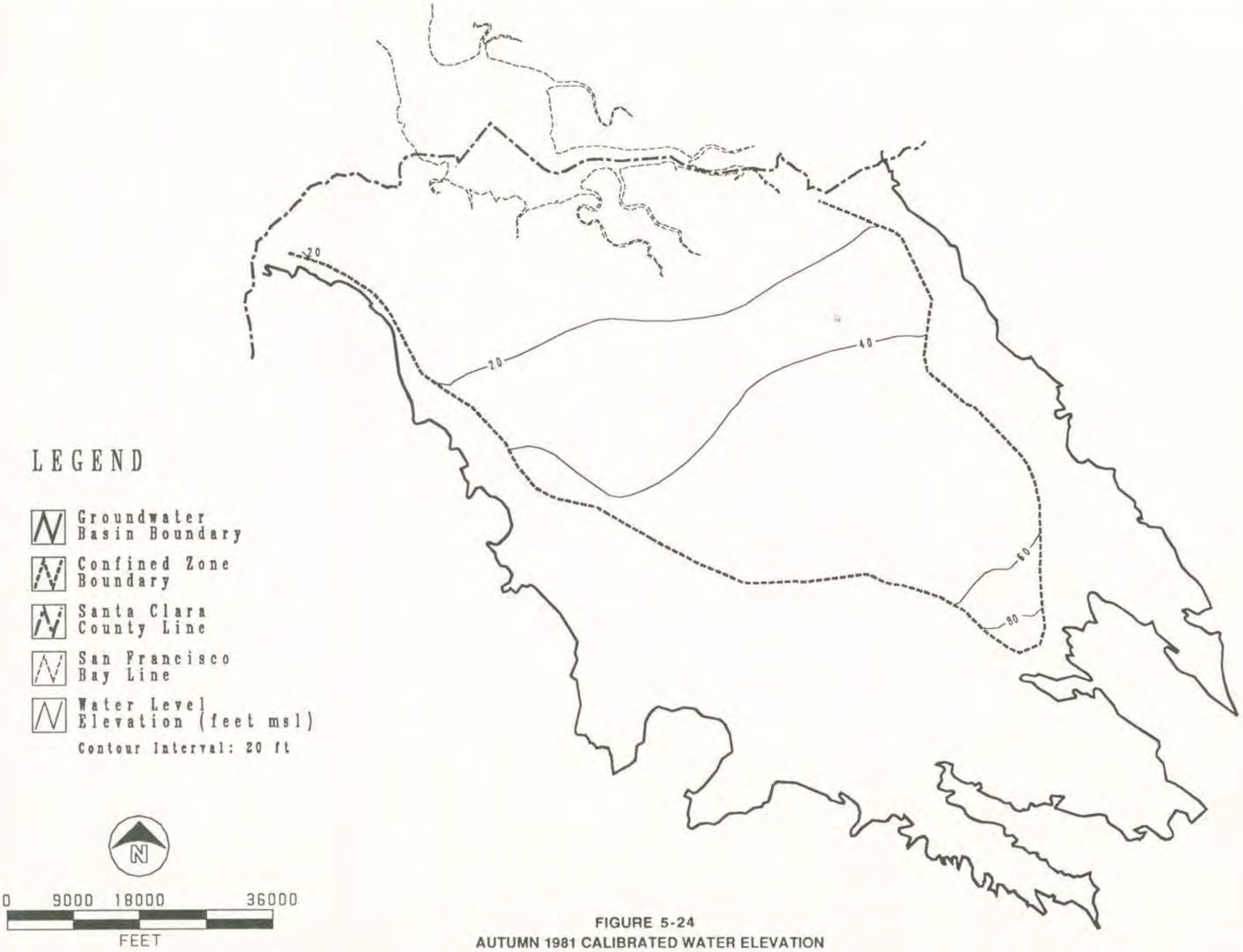


FIGURE 5-24
AUTUMN 1981 CALIBRATED WATER ELEVATION
MODEL LAYER 1

CONTL1.AML SFO27295.BM

October 12, 1992

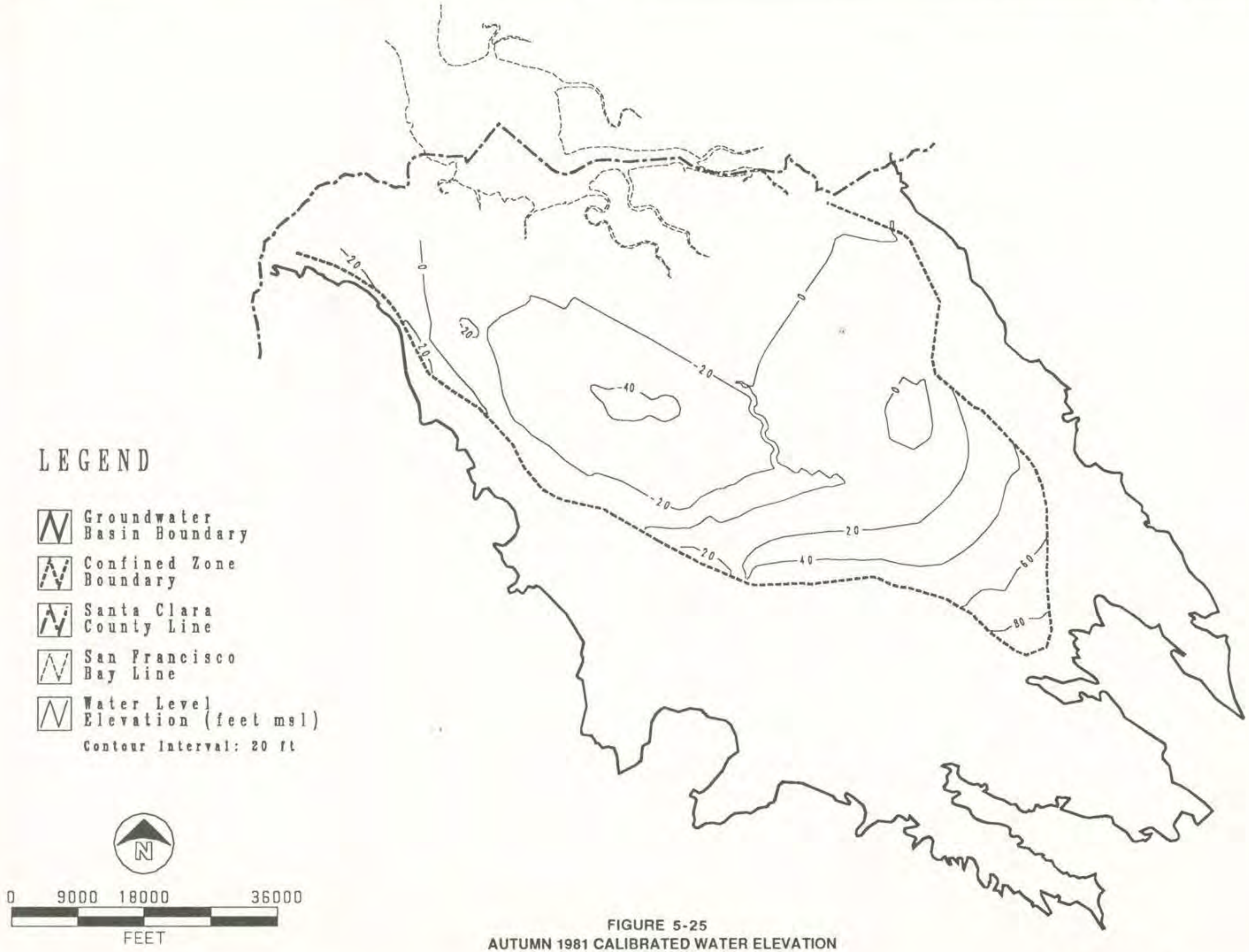


FIGURE 5-25
AUTUMN 1981 CALIBRATED WATER ELEVATION
MODEL LAYER 2

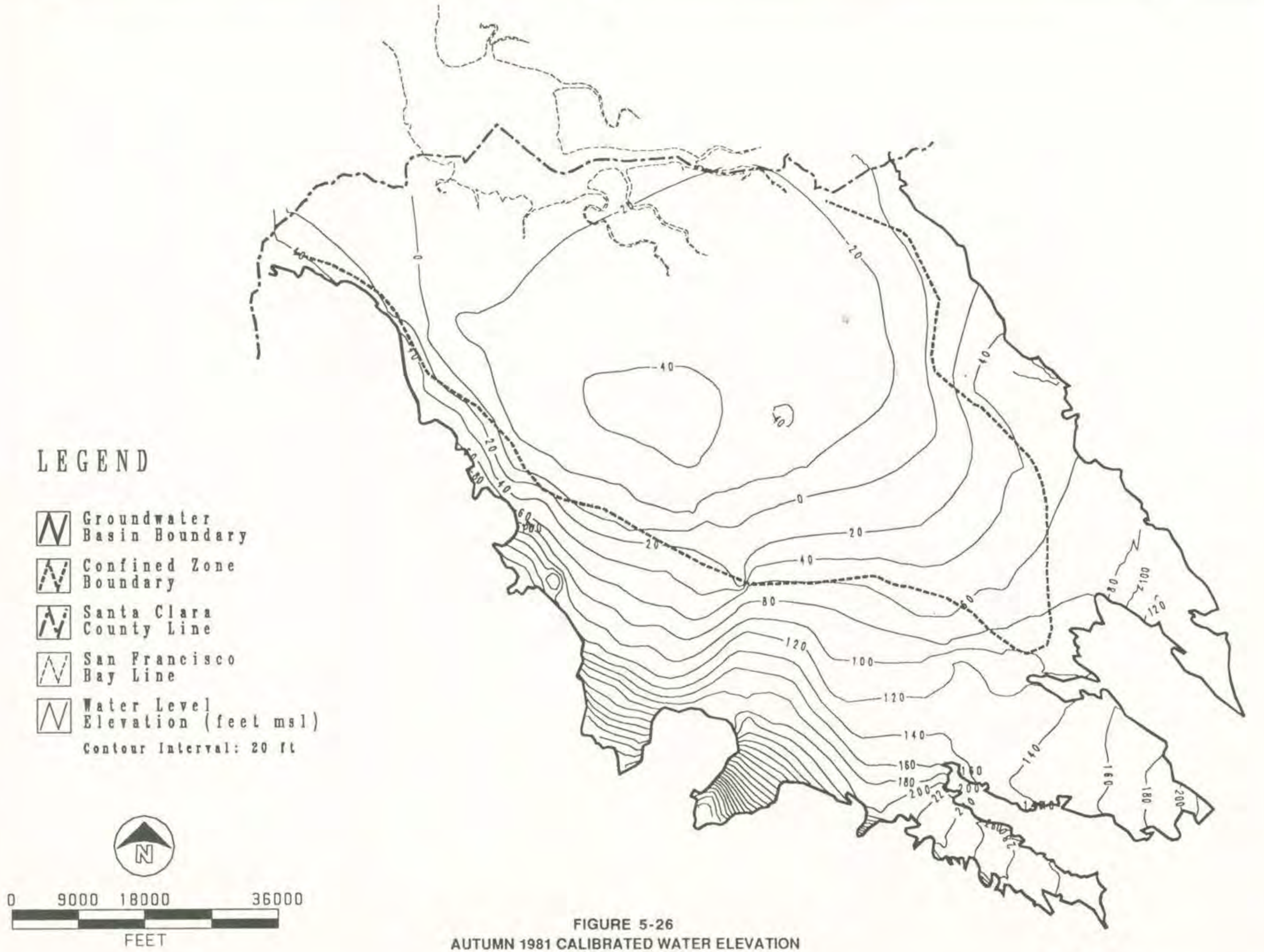


FIGURE 5-26
AUTUMN 1981 CALIBRATED WATER ELEVATION
MODEL LAYER 3

CH2M HILL

CONTL3.AML SFO27295.BM

October 12, 1992

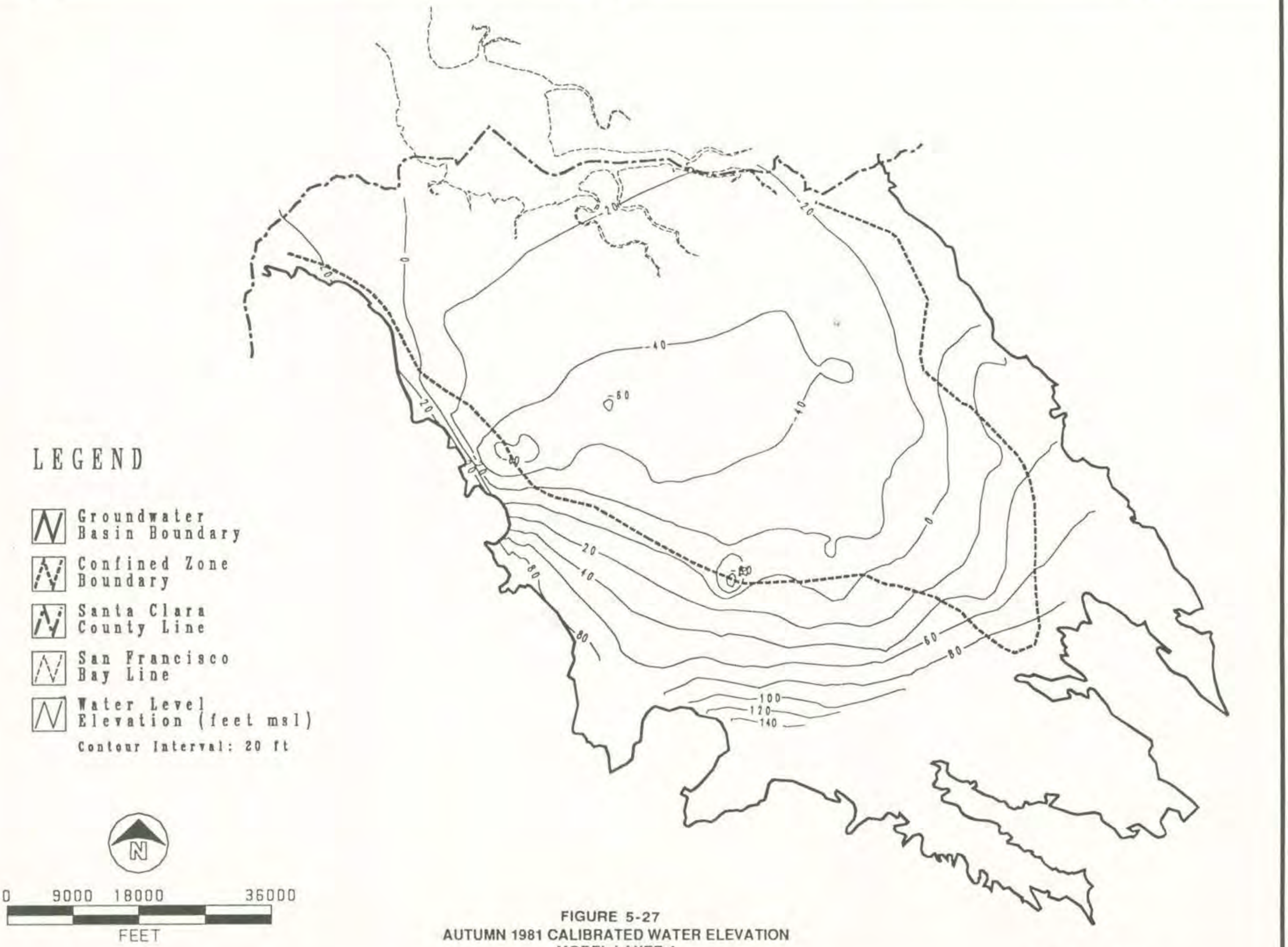


FIGURE 5-27
AUTUMN 1981 CALIBRATED WATER ELEVATION
MODEL LAYER 4

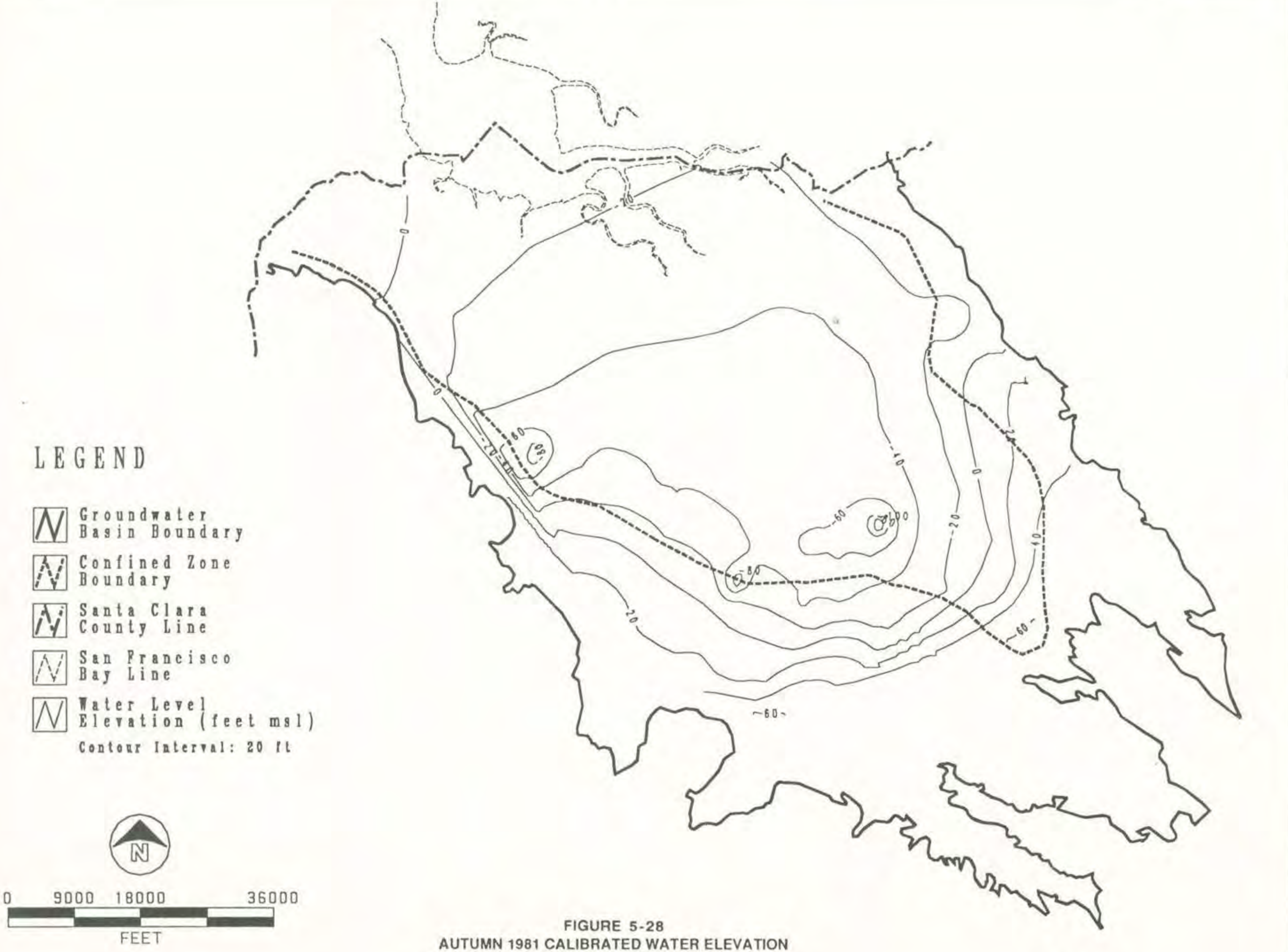


FIGURE 5-28
AUTUMN 1981 CALIBRATED WATER ELEVATION
MODEL LAYER 5

CONTLS.AML SFO27295.BM

CH2M HILL

October 12, 1992

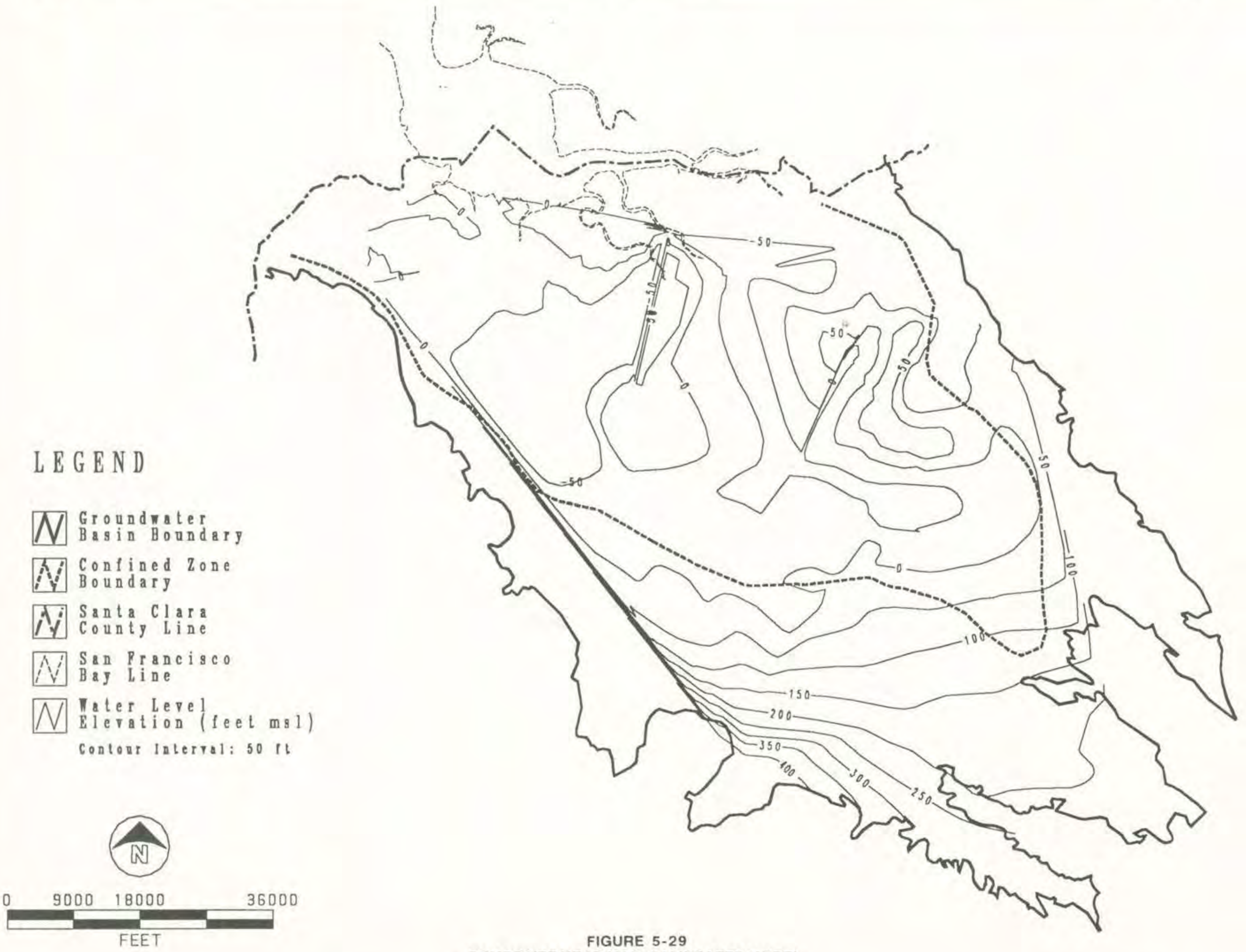


FIGURE 5-29
COMPOSITE HEAD MAP–CALIBRATED MODEL

COMSS.AML SFO27295.BM

CH2M HILL

October 19, 1992

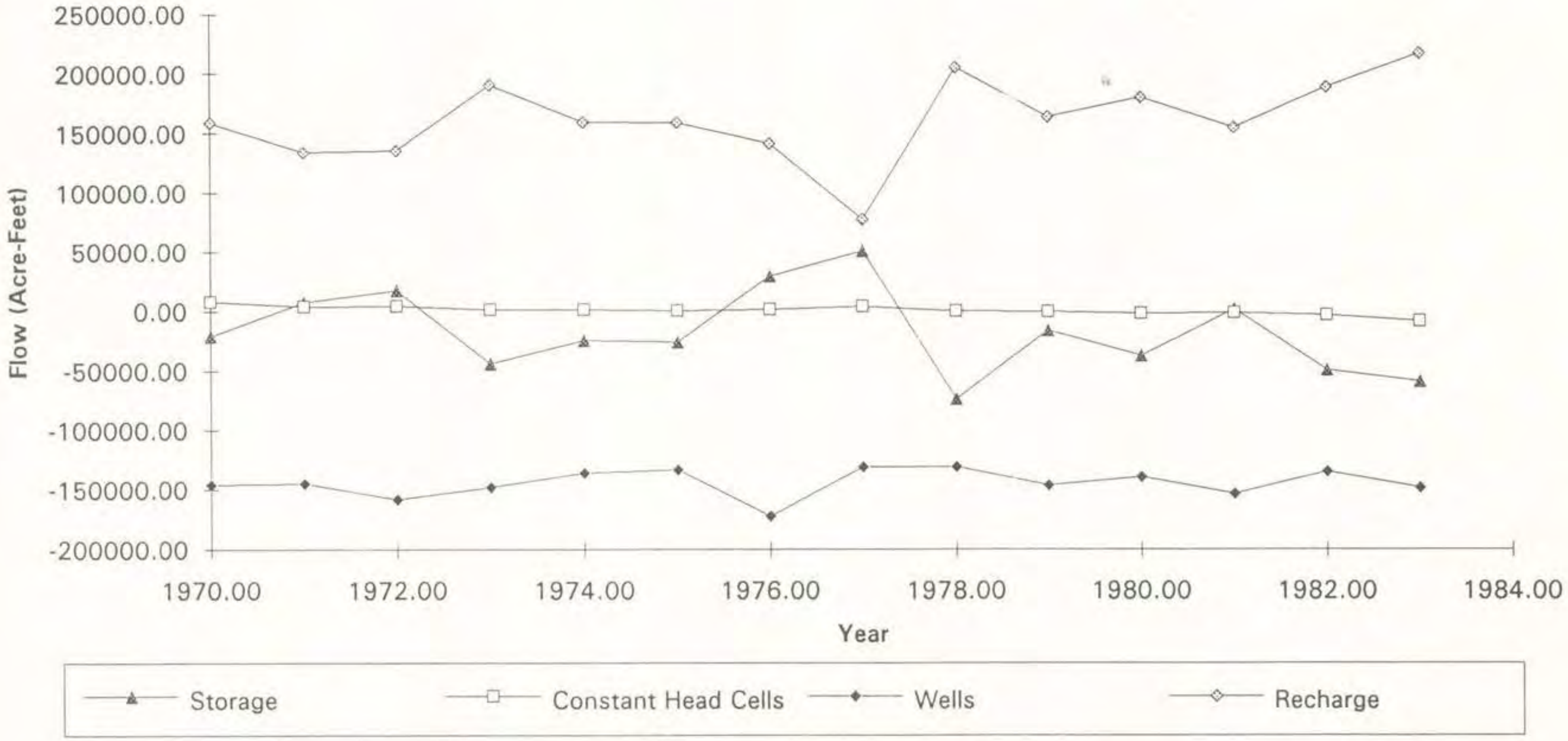


FIGURE 5-30

ANNUALIZED TRANSIENT WATER BUDGET

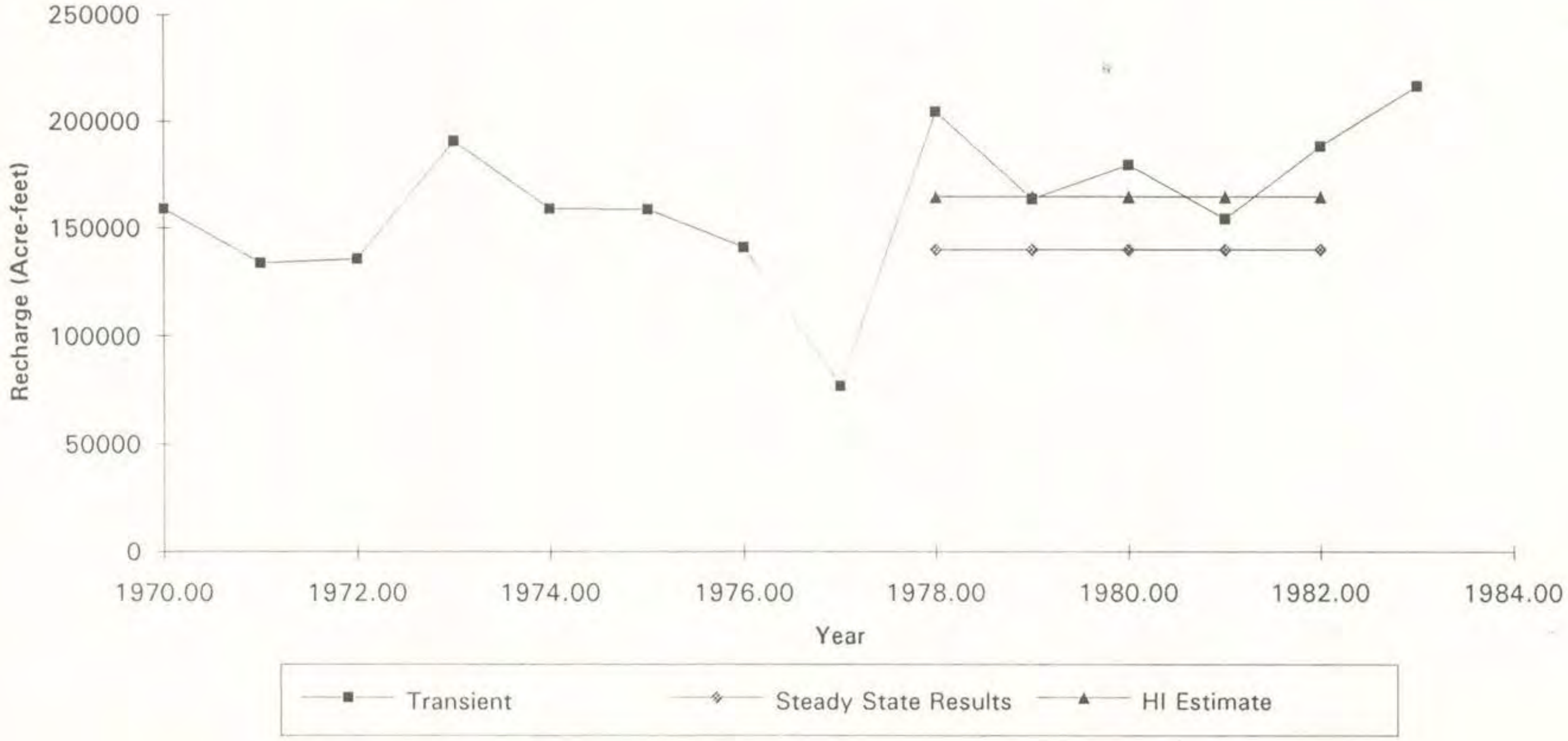


FIGURE 5-31
STEADY STATE AND TRANSIENT RECHARGE

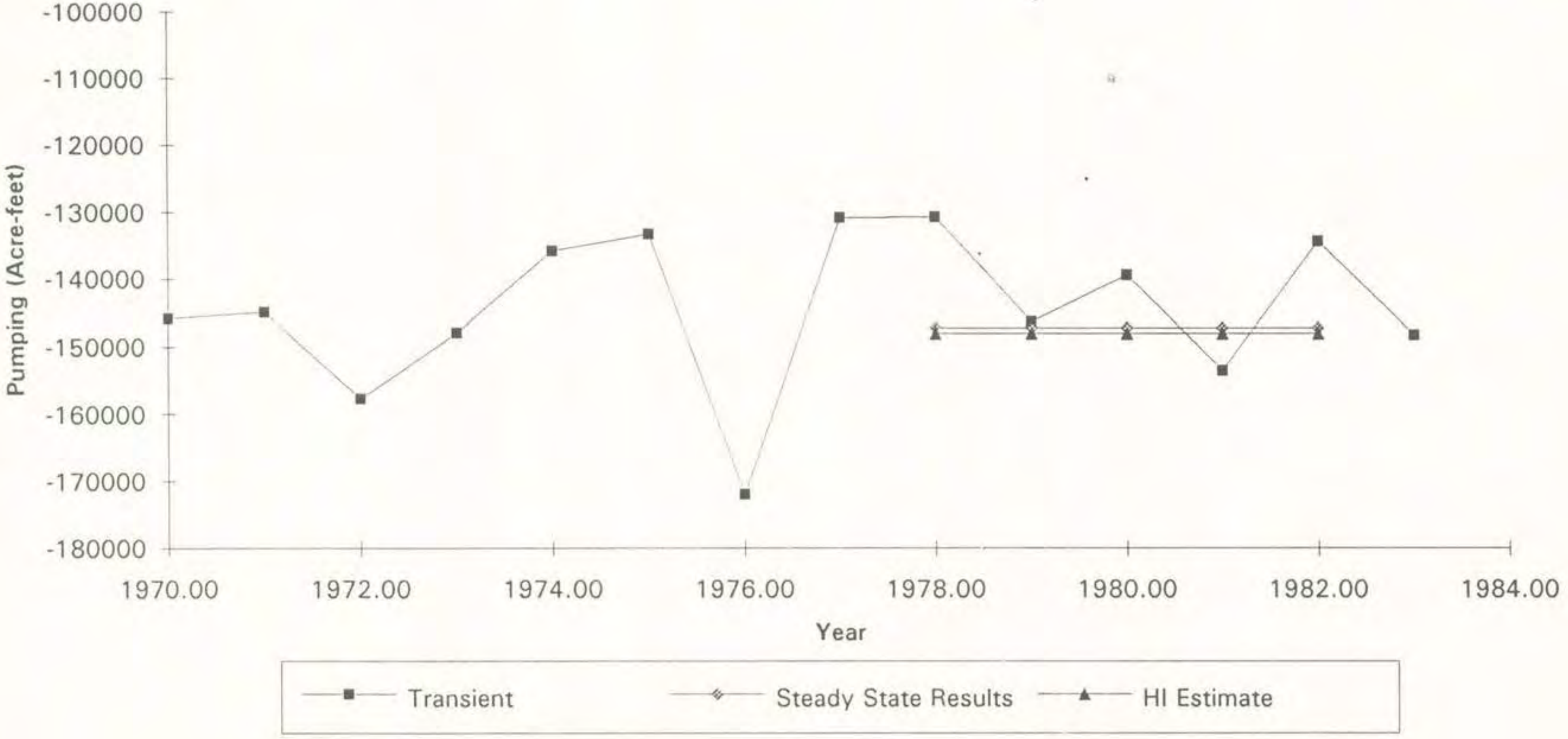


FIGURE 5-32

STEADY STATE AND TRANSIENT PUMPING

CH2M HILL

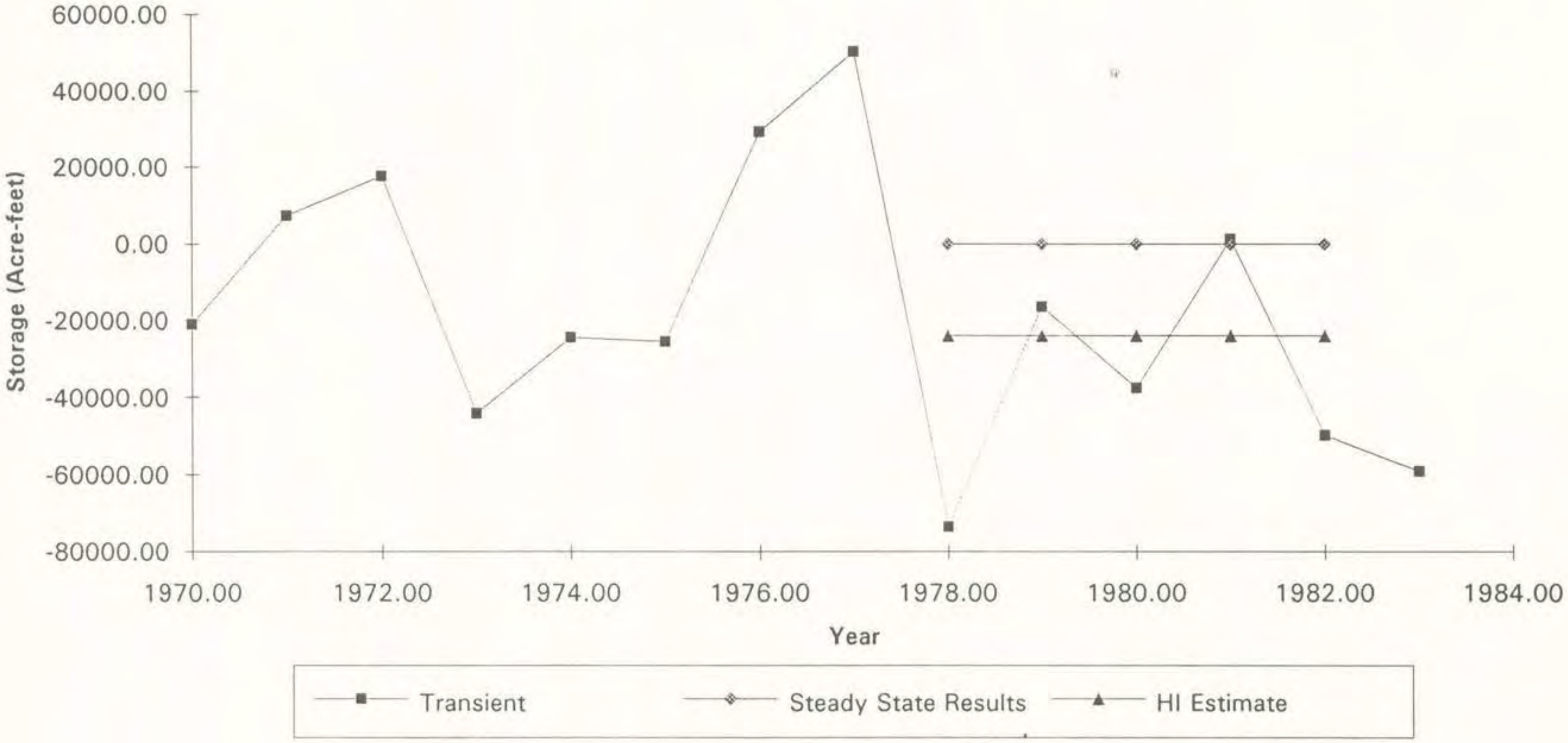


FIGURE 5-33
STEADY STATE AND TRANSIENT STORAGE VALUES

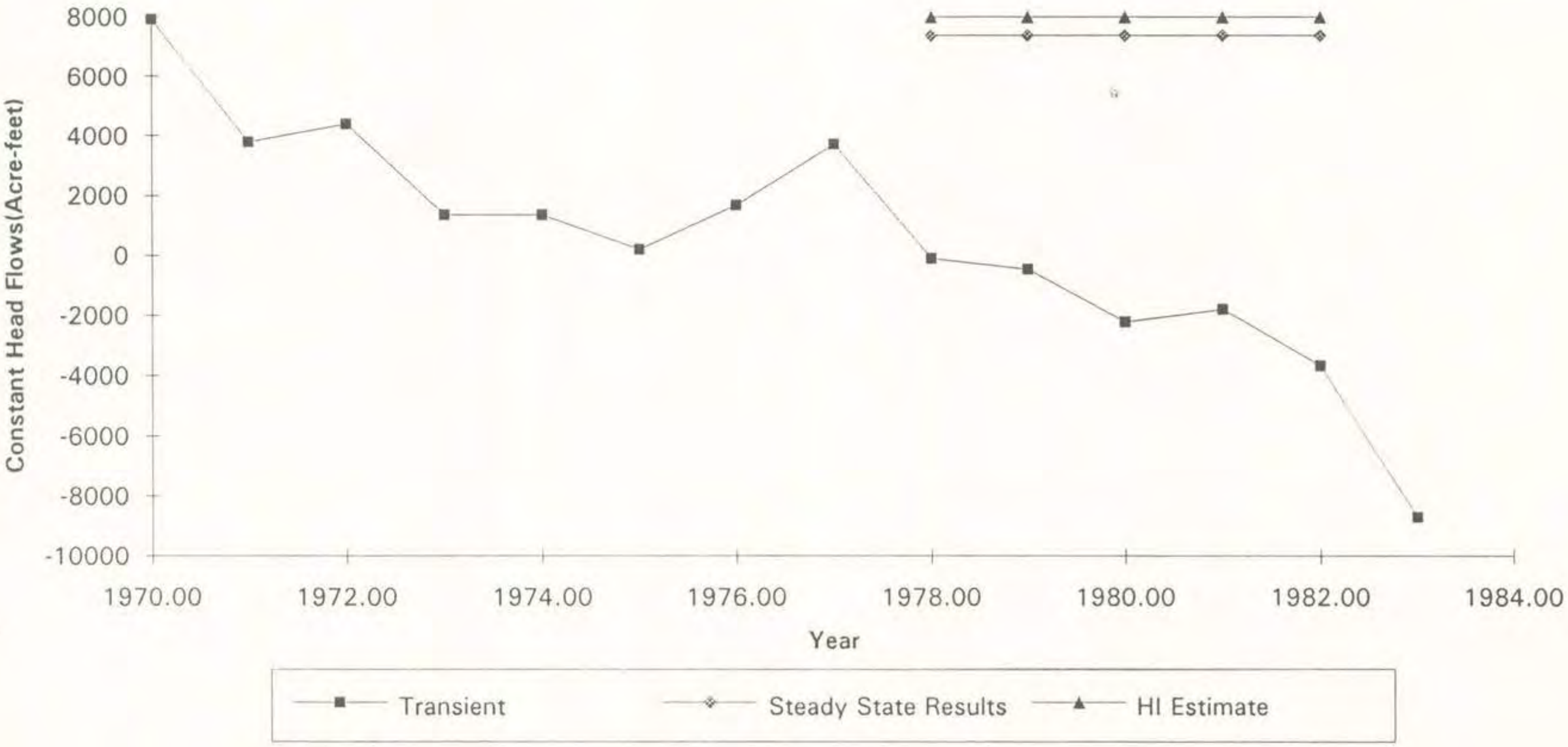


FIGURE 5-34
STEADY STATE AND TRANSIENT CONSTANT HEAD FLOW

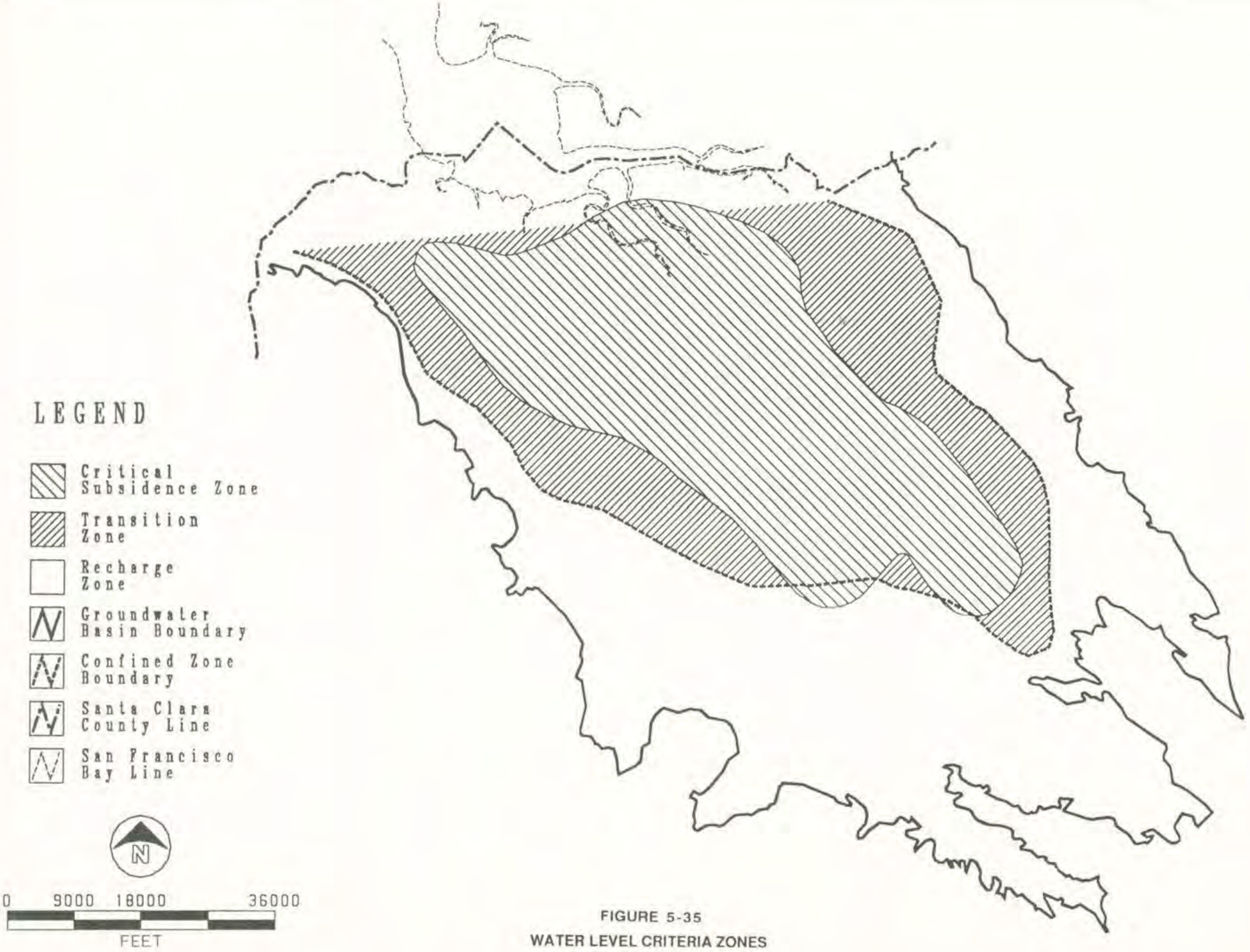


FIGURE 5-35

WATER LEVEL CRITERIA ZONES

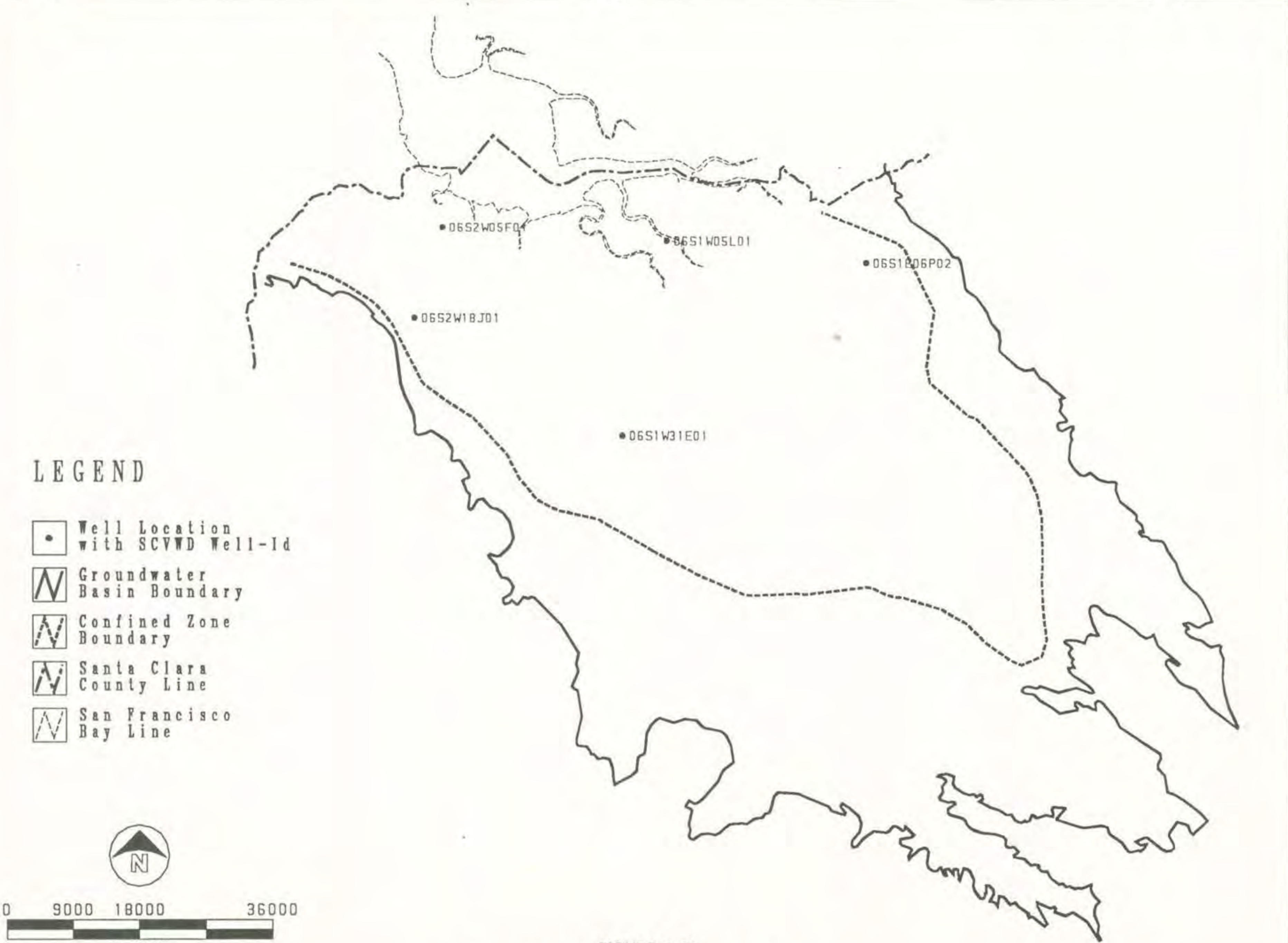


FIGURE 5-36
VERIFICATION WELL LOCATIONS, MODEL LAYER 1

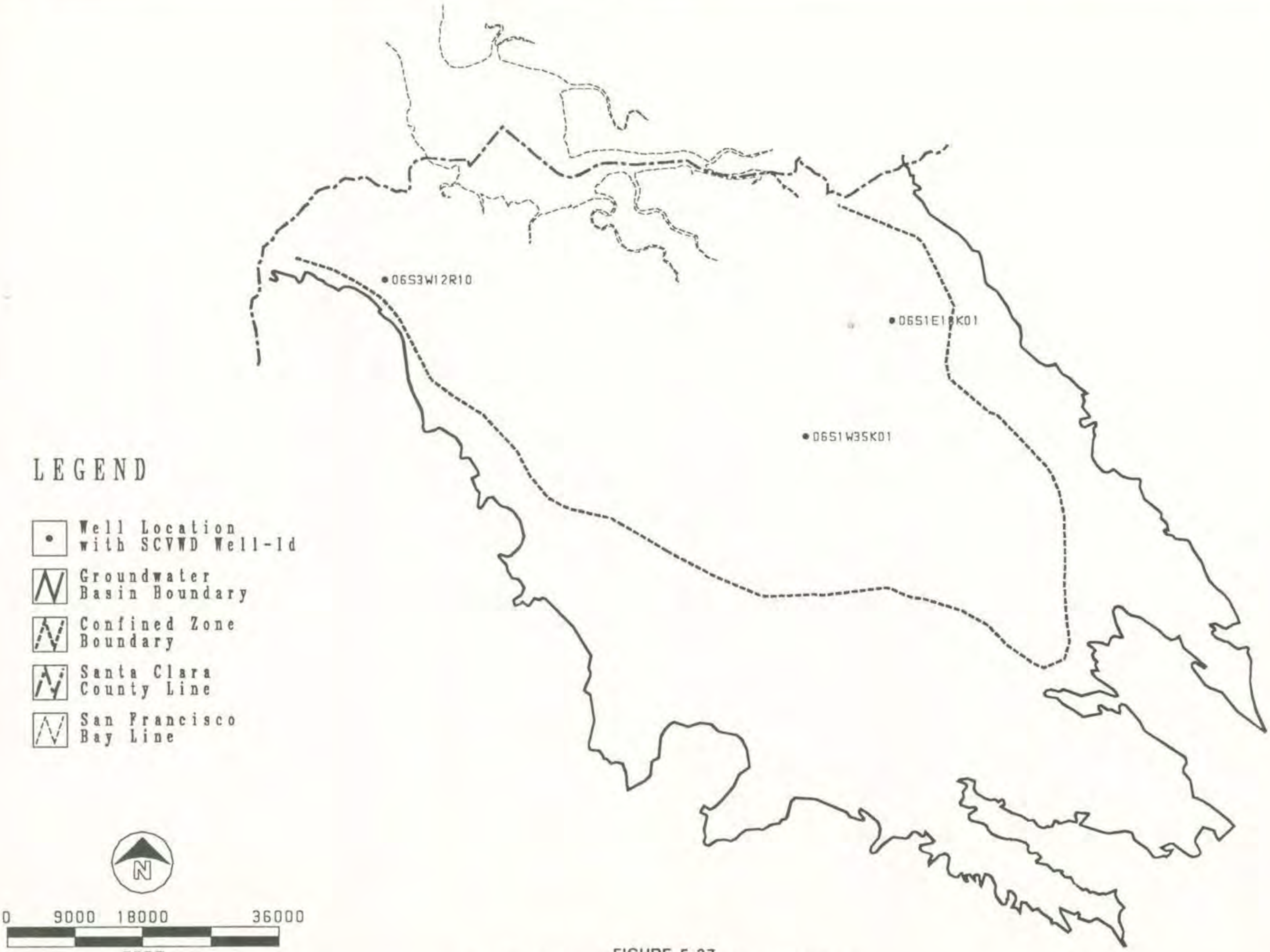


FIGURE 5-37
VERIFICATION WELL LOCATIONS, MODEL LAYER 2

CWELL.AML SFO27295.BM

CH2M HILL

October 14, 1992

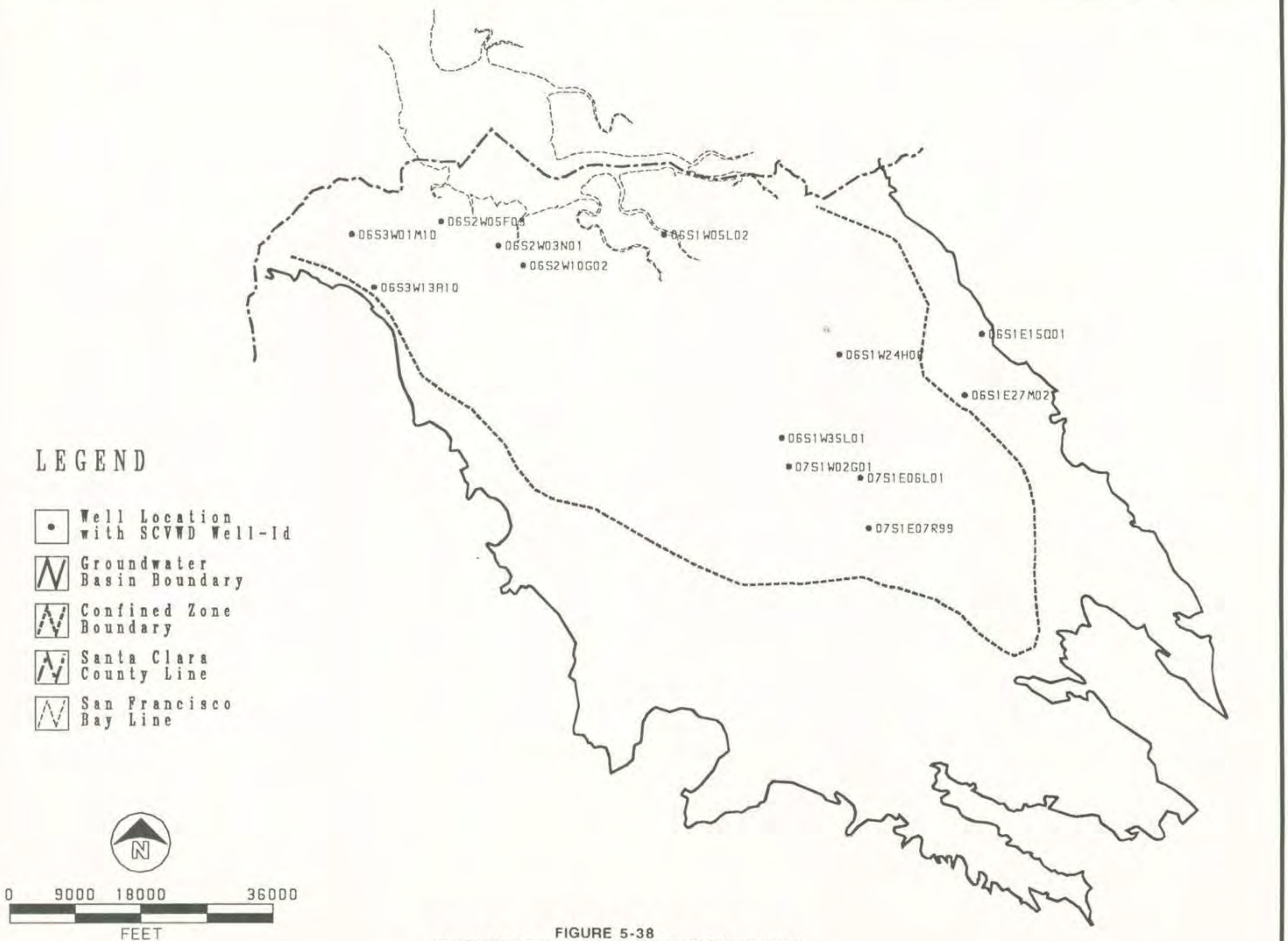


FIGURE 5-38
VERIFICATION WELL LOCATIONS, MODEL LAYER 3

CWELL.AML SFO27295.BM

CH2M HILL

October 14, 1992

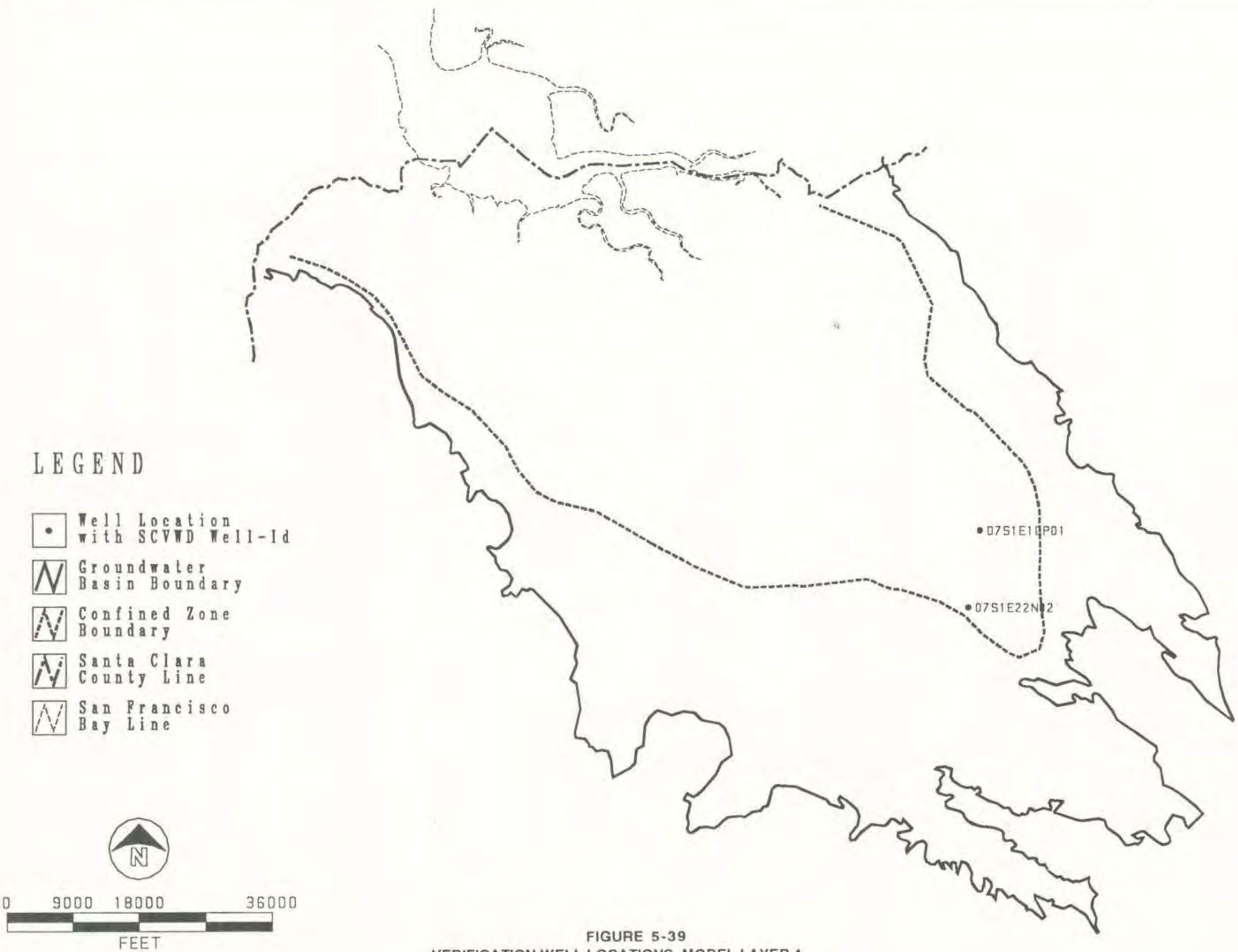


FIGURE 5-39
VERIFICATION WELL LOCATIONS, MODEL LAYER 4

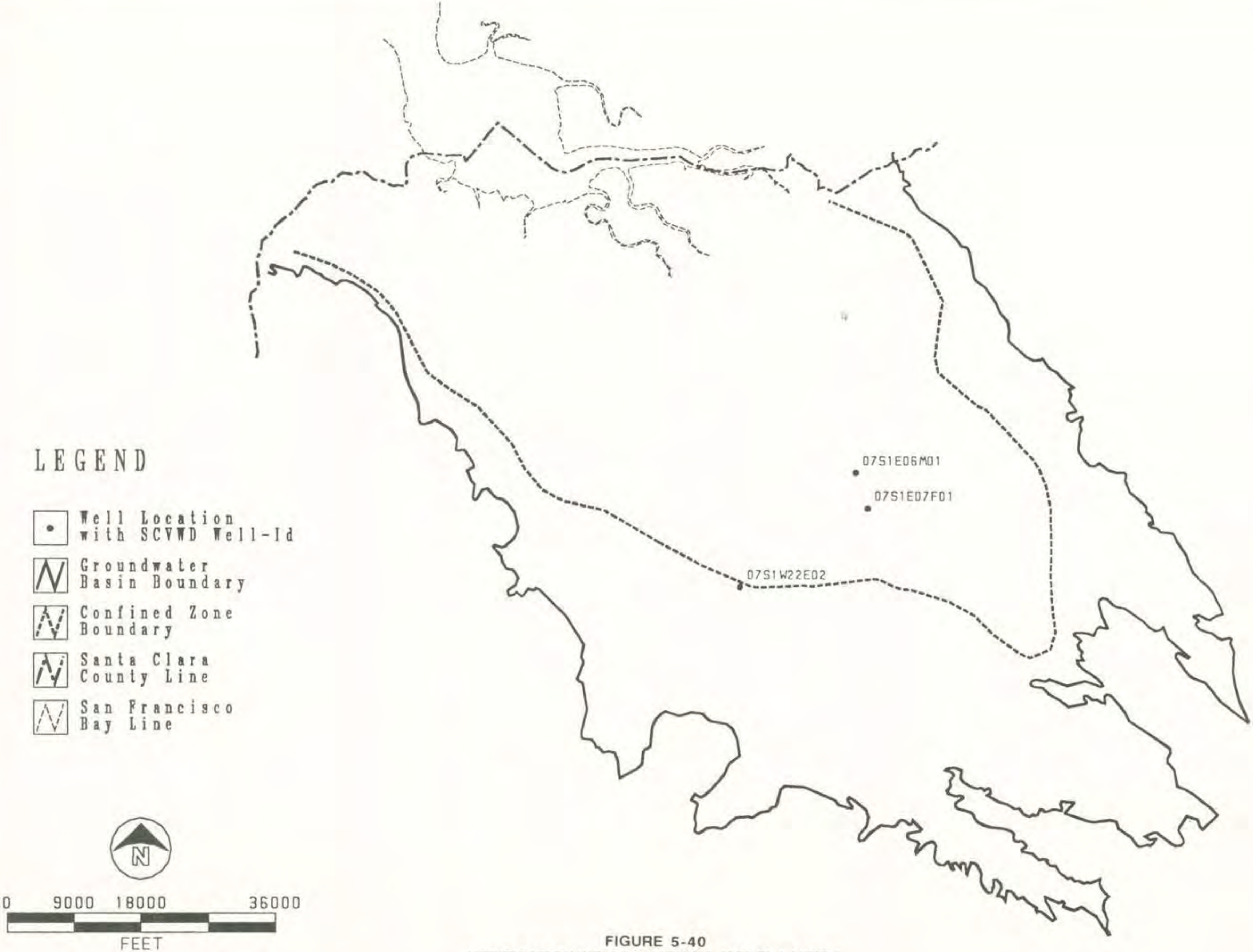


FIGURE 5-40
VERIFICATION WELL LOCATIONS, MODEL LAYER 5

CWELL.AML SFO27295.BM

October 14, 1992

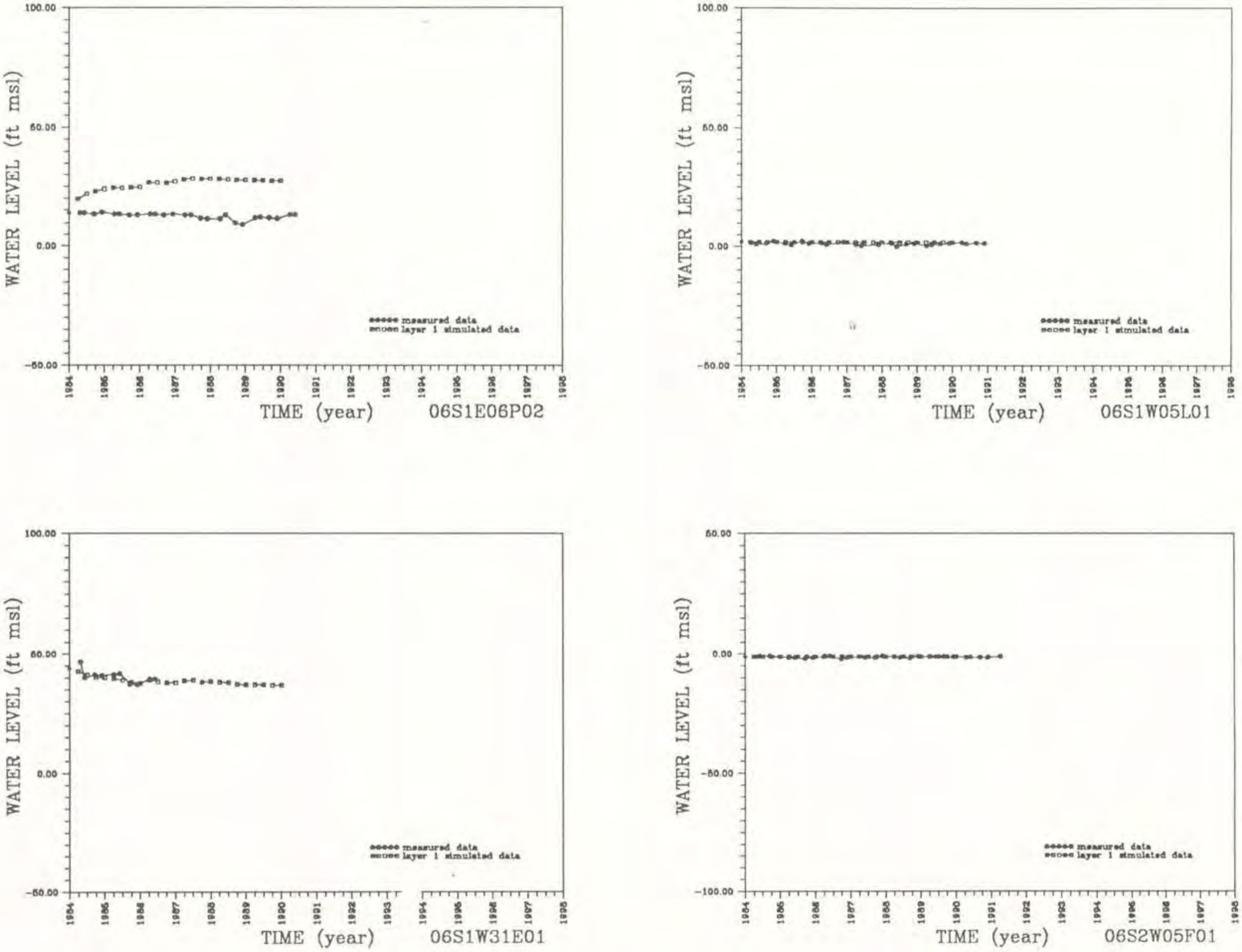


FIGURE 5-41a
VERIFICATION HYDROGRAPHS, MODEL LAYER 1

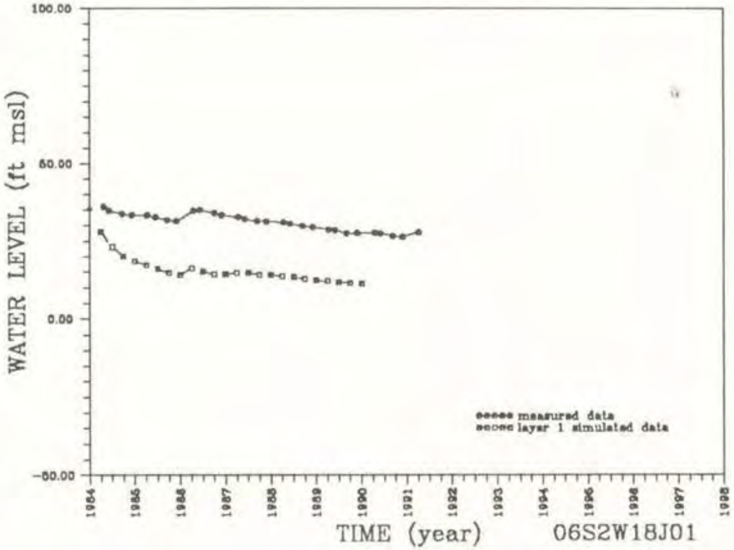
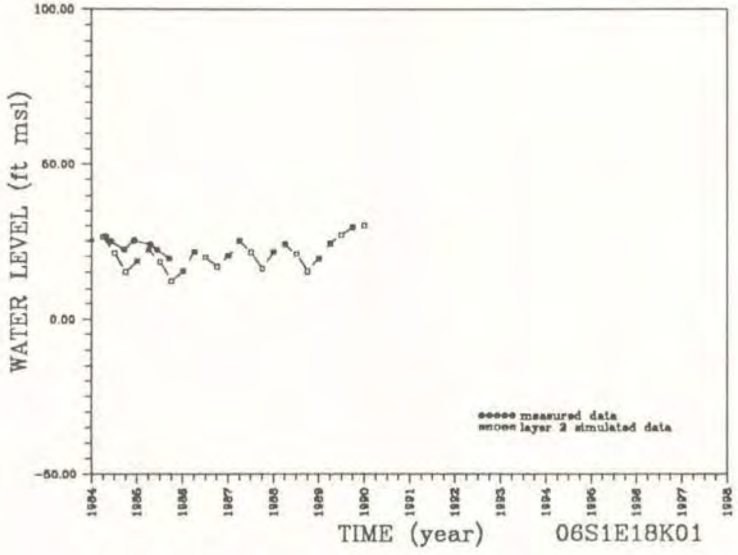
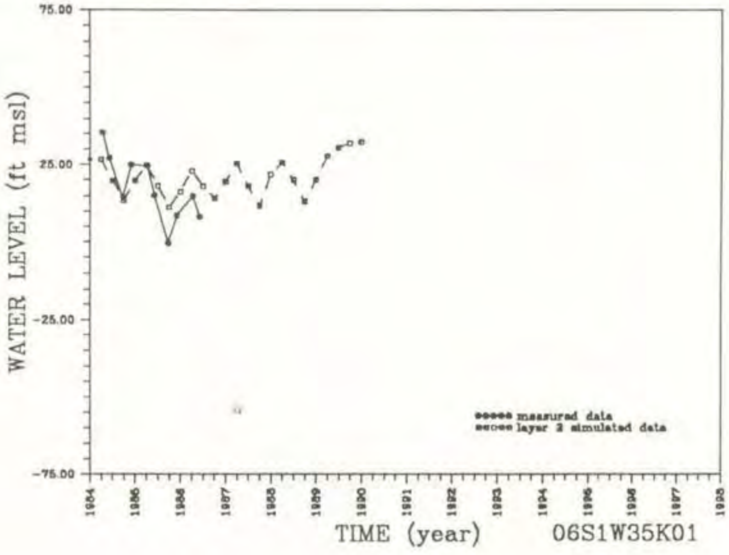


FIGURE 5-41b
VERIFICATION HYDROGRAPHS, MODEL LAYER 1





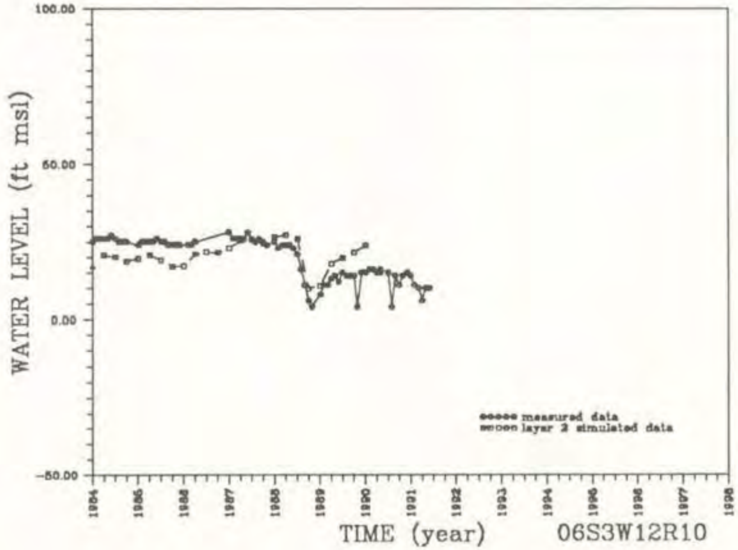


FIGURE 5-42
VERIFICATION HYDROGRAPHS, MODEL LAYER 2

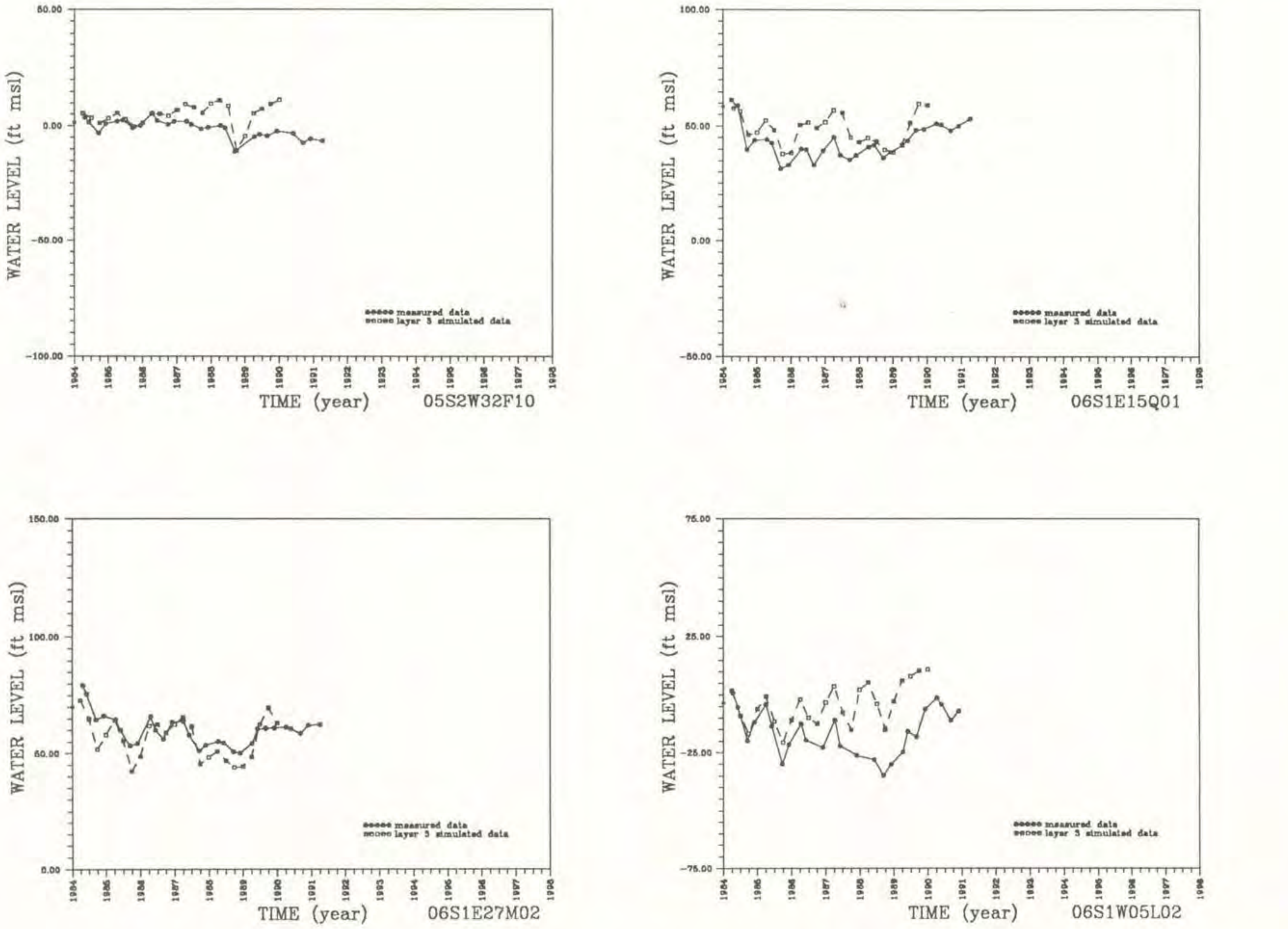


FIGURE 5-43a
VERIFICATION HYDROGRAPHS, MODEL LAYER 3

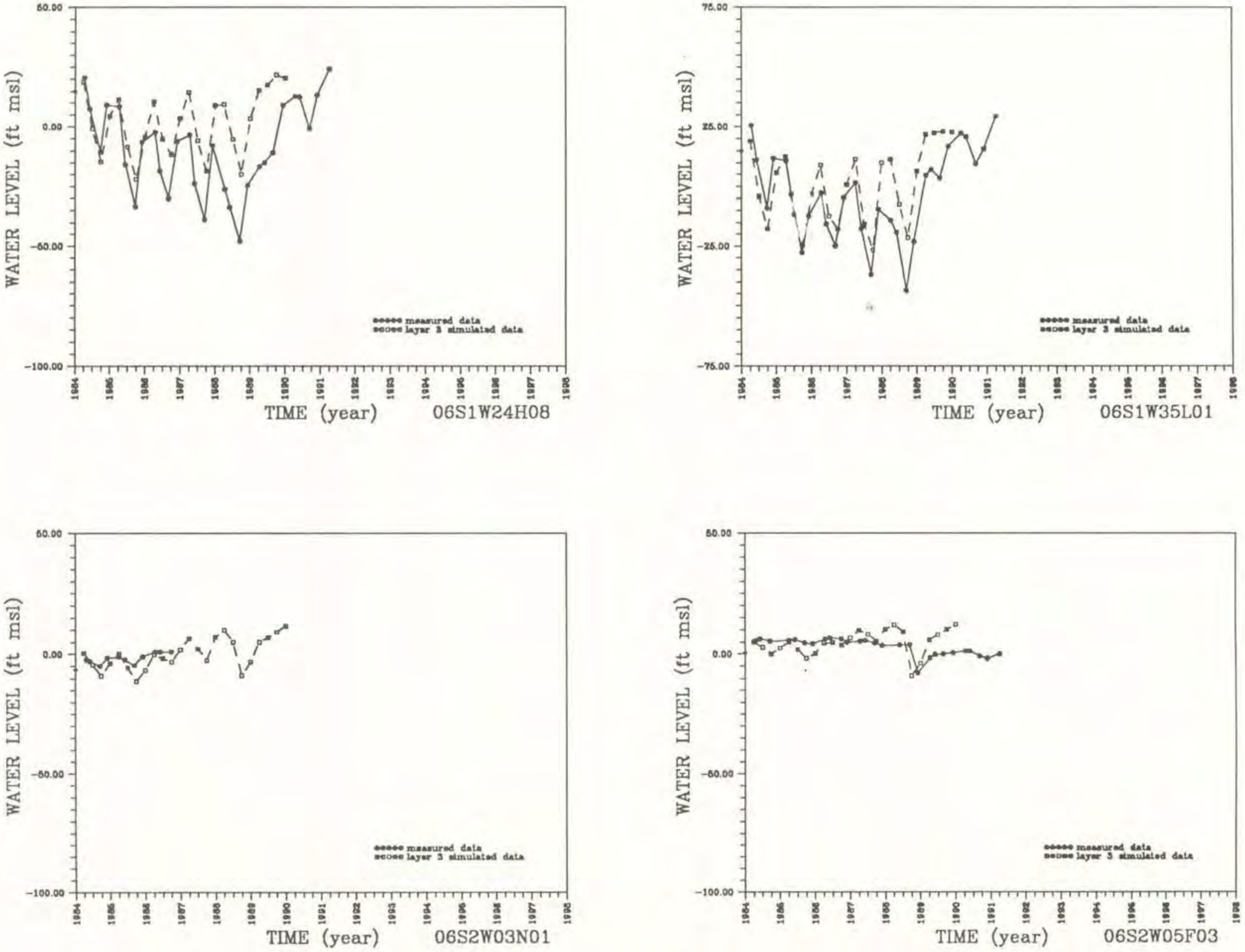


FIGURE 5-43b
VERIFICATION HYDROGRAPHS, MODEL LAYER 3

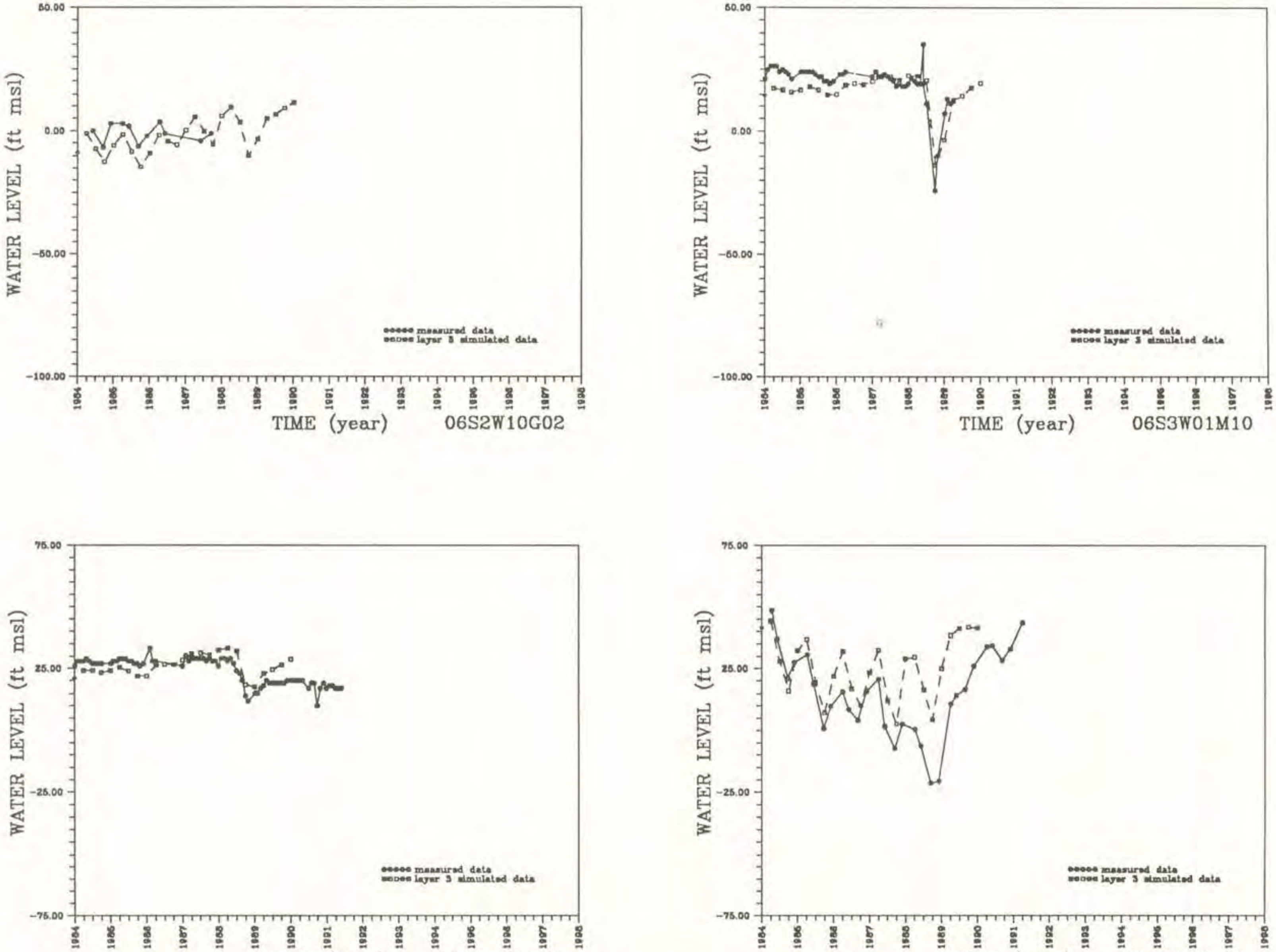


FIGURE 5-43c
VERIFICATION HYDROGRAPHS, MODEL LAYER 3

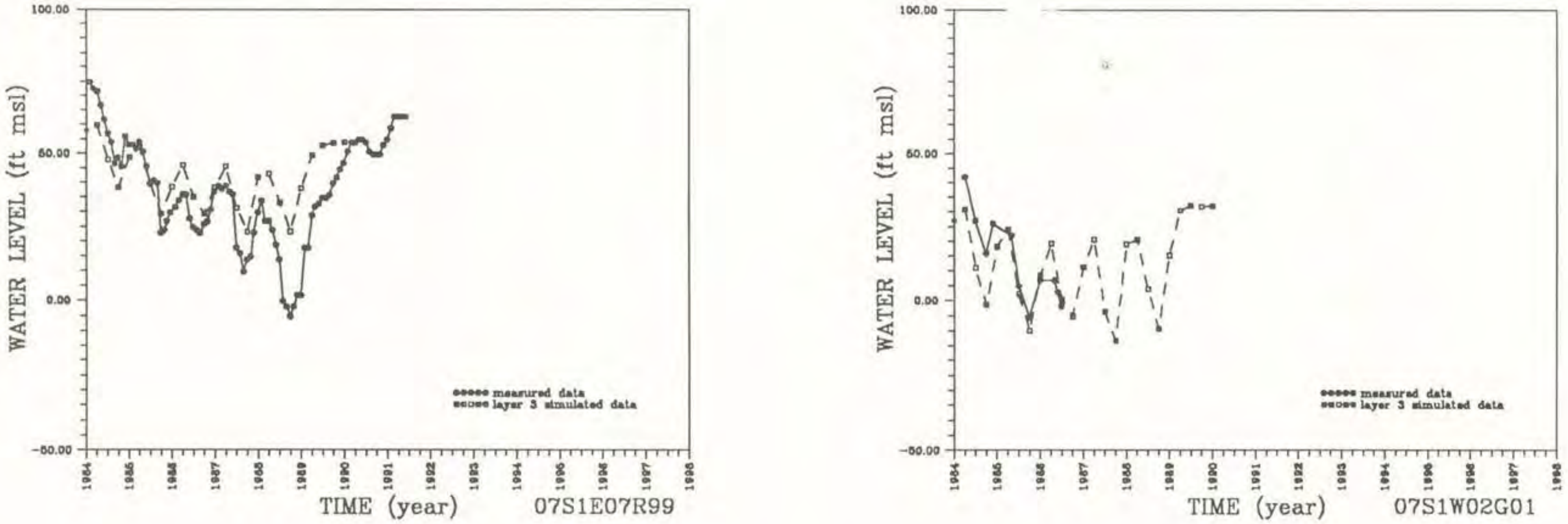


FIGURE 5-43d
VERIFICATION HYDROGRAPHS, MODEL LAYER 3

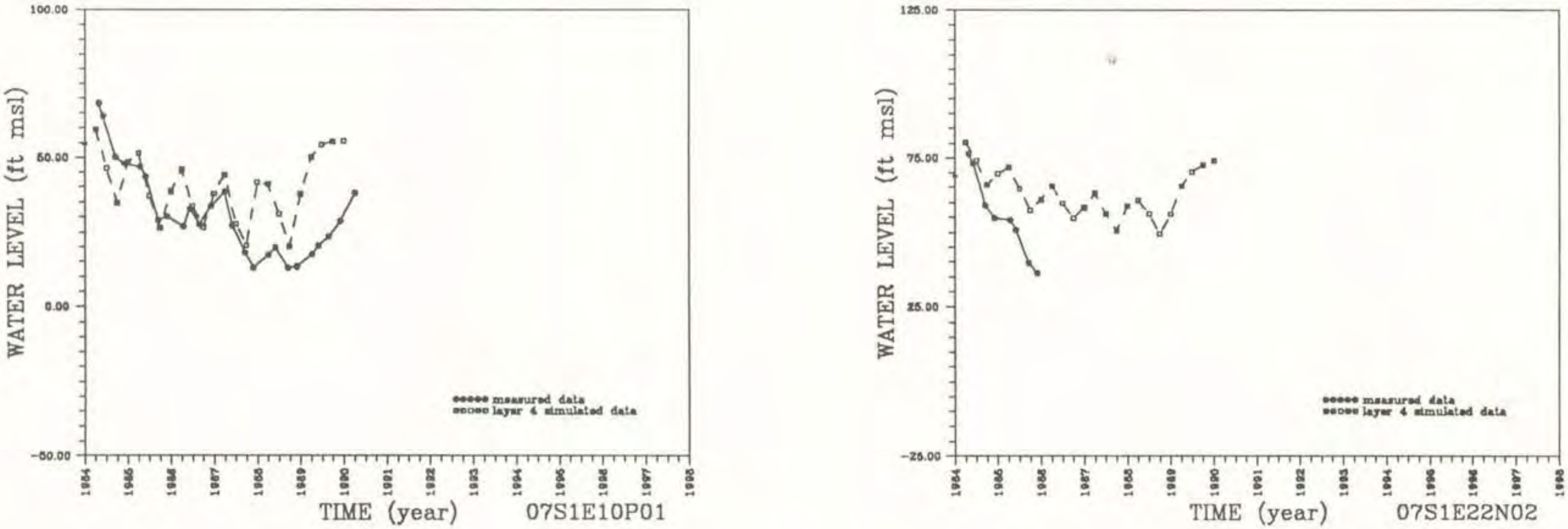


FIGURE 5-44
VERIFICATION HYDROGRAPHS, MODEL LAYER 4

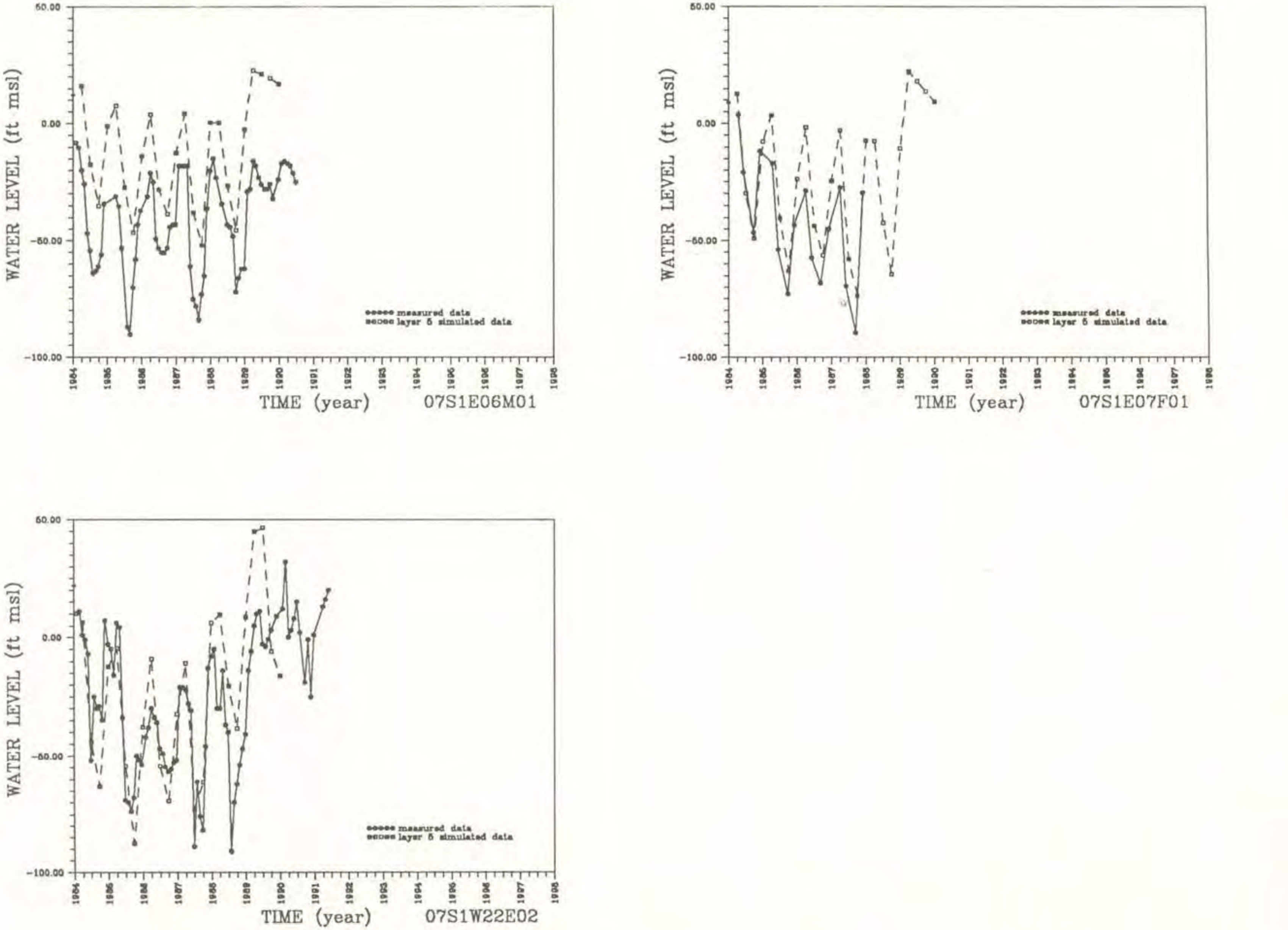


FIGURE 5-45
VERIFICATION HYDROGRAPHS, MODEL LAYER 5

Section 6

Uncertainties and Recommendations

The numerical model described in the previous sections provides the SCVWD and City of San Jose with a tool for predicting future groundwater conditions in the Northern Santa Clara Valley. As with all models, model accuracy increases with continued refinement. The model is based on data available during the project; uncertainty in the data, and corresponding uncertainty in the data analyses, should be refined with continued investigations and data analyses. The purpose of this section is to outline uncertainties in the conceptual and numerical models, and to suggest future data collection and analyses that should be undertaken by the SCVWD and City of San Jose. The main recommendations, in order of importance, are: continuing calibration; performing sensitivity analyses; improving measurements of the groundwater budget; conducting additional field monitoring; adding additional model packages; and constructing wellfield scale models.

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6.1 Continued Calibration and Sensitivity Analyses

Model calibration is an ongoing process that reinforces and increases confidence in model results. Continued calibration using new data is an important exercise to retain the model's accuracy and reliability. Additional data must be incorporated into the model as they become available, and existing data reevaluated as necessary. Incorporation of additional data into the model will help refine both the conceptual and numerical models. Suggested model refinements and methodologies are presented in the following paragraphs.

The horizontal hydraulic conductivity zonation and parameter values in the conceptual and numerical models are based on lithology and available specific capacity data, respectively. The zonation and parameter values should be checked after incorporating additional lithologic data and aquifer test data.

Refining the extent of the major aquitard (Model Layer 2) is also important. Section 5.1.2 details how the extent of Model Layer 2 was reduced during calibration, and the depth of Model Layer 1 increased. Hydrographs near downtown San Jose, however, suggest that the true extent of the confining zone likely lies between the revised extent of the major aquitard and the extent of the confined zone described by the SWRCB (1955) (Figure 5-3). Analyses of additional hydrographs, coupled with additional model simulations will be needed to refine the extent of the confined zone.

Once the current hydraulic conductivity zonation has been revised or validated, statistically-based automatic parameter estimation should be undertaken. This effort would also serve as a sensitivity analysis. The recently-released parameter estimation package, MODFLOWP, provides the necessary parameter estimation capabilities (Hill, 1992). In addition to refining parameter estimates, the statistical results of MODFLOWP may provide additional insight into the validity of the conceptual model.

6.2 Additional Field Monitoring

Incorporating more precise and more complete data coverage into the model will improve model accuracy. A field program should be undertaken to expand the monitoring well network, conduct aquifer tests, measure depth-specific pumping in existing wells, and gauge groundwater inflows and outflows to streams.

Currently, the model uses water level measurements supplied by retailers and municipalities from various production and monitoring wells. These water levels may not reflect water levels from a specific depth because the perforated intervals of these wells are typically long, and cross many producing zones. To characterize the multilayer Santa Clara Valley Basin aquifer system more accurately, discrete water level measurements from each depth layer are needed.

A monitoring program should be initiated to accurately characterize individual piezometric surfaces of the groundwater basin. Suitable abandoned wells could be incorporated into the groundwater monitoring network. Installing additional monitoring wells may be necessary if suitable existing wells cannot be located.

The lack of available aquifer test data was noted in Section 3.2.4. Aquifer tests provide the data needed to estimate aquifer parameters; without additional aquifer tests, parameter values lack confirmation by actual field measurements. Sensitivity analyses may indicate that an aquifer testing program is critical for substantiating and refining model parameter values, including depth-specific measurements of horizontal and vertical hydraulic conductivities, storativity, and specific yield.

The interaction between streams and the shallow groundwater is currently poorly understood. The quantity of groundwater flowing into San Francisco Bay through streams is unknown. A monitoring program to gauge stream gains from, and losses to, the shallow groundwater would provide an estimate for an important aspect of the groundwater basin's water budget.

Pumping in the numerical model is currently distributed within individual wells based on the length of perforated intervals. This assumption was necessary because depth-specific flow data are unavailable. A field program to measure depth-specific flows into pumping wells will improve the accuracy and dependability of the model.

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6.3 Improved Water Budget Calculations

The water budget incorporated into the numerical model proved sufficient for the modeling effort; however, it is based on a number of generalized assumptions. Refining the groundwater budget will improve both the overall and the local accuracy of the model. Specific areas of potential improvement include: better estimates of deep percolation from rainfall; estimating effects of minor, ungauged streams; improving estimates of mountain-front recharge; and more accurate monitoring of facility recharge.

Facility recharge is estimated with the BNDFLO program. Field checks of the quantities of water recharged, along with estimates of seepage back into streams (tail water), will enhance the numerical model.

Direct deep percolation of rainfall was estimated throughout the basin using an empirical formula. This method did not account for variations in topography, vegetative cover, or land use. Model results suggest that Model Layer 1 over the confined zone receives too much water from direct percolation. Refinements of the direct percolation calculations must account for the aforementioned factors.

Minor, ungauged streams likely do not add significant amounts of water to the groundwater basin. Local effects of minor stream recharge, however, may not be simulated unless the minor stream recharge is included in the groundwater model.

The assumption that 95 percent of the basinwide groundwater pumping sufficiently simulates the major stresses on the basin requires validation. The effect of including all of the pumping on the water budget should be studied. The extra pumping may affect the amount of water flowing in and out of constant head cells.

Hetch-Hetchy water deliveries were included with other sources of imported water for calculation of water losses from SCVWD transmission lines. It is likely that the estimated amount of Hetch-Hetchy water lost from distribution lines (8.0%) is approximately correct. However, Hetch-Hetchy water is not treated by the SCVWD prior to distribution, and therefore does not flow through the major distribution lines shown on Figure 4-27. Losses of Hetch-Hetchy water to the groundwater should be distributed along the Hetch-Hetchy line that passes through the Santa Clara Valley.

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6.4 Additional Model Packages

Adding supplementary modules to MODFLOW broadens the scope of potential calibrations and simulations. Particularly, the SCVWD and the City of San Jose should incorporate the Interbed-Storage package (Leake and Prudic, 1988). The Interbed-

Storage Package (IBS1) accounts for water released during subsidence, and calculates subsidence from groundwater withdrawal. Incorporation of this package would permit the simulation of subsidence using the numerical model, providing a more realistic prediction of future groundwater availability.

The Interbed-Storage package must be incorporated after other aspects of the groundwater model are refined. Following additional model calibration without subsidence, calibration of a period with subsidence will be necessary to incorporate the IBS1 package. This stepwise calibration procedure avoids simultaneous adjustment of an excessive number of parameters.

Either the MODFLOW drain or river packages should be added to simulate interactions between groundwater and streams above the confined zone. These interactions were assumed to be minor in Section 4.1; however, this may have introduced inaccuracies in Model Layer 1 results. The drain or river packages should be calibrated to measured flows and stages of the streams above the confined zone.

Depending on local groundwater levels, addition of the MODFLOW river or stream packages may lower water table elevations in Model Layer 1, requiring recalibration of Model Layer 1 hydraulic conductivities. Removing groundwater through streams may additionally help remedy the problem of excess water in Model Layer 1, discussed in Section 5.3.

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6.5 Wellfield Scale Models

The necessarily coarse spatial discritization of the basinwide groundwater flow model precludes site-specific analyses. Model cells have minimum dimensions of 1,000 feet on a side. Piezometric surface variations within approximately 500 feet of any well can not be simulated with the basinwide groundwater flow model.

Wellfield scale models with finer spatial discritization could simulate local piezometric variations. Wellfield scale models could replicate discrete portions of the basinwide groundwater flow model. Boundary conditions for the wellfield scale models would be derived from the basinwide model.

Section 7

References

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Appendix A

Summary of GWTAC Concerns

This appendix summarizes the comments offered by the GWTAC members on the various stages of the model. As mentioned previously, several meetings (both formal and informal) were held between the GWTAC members and the modeling team. At these meetings, the modeling work completed to date, as well as modeling work planned, was discussed in detail. GWTAC members provided comments on the modeling progress and plans in the form of letters written after each meeting. These letters are on file with the SCVWD. Table A-1 summarizes the GWTAC comments, and indicates how the comments were incorporated into the groundwater model.

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Table A-1
Summary of GWTAC Recommendations

GWTAC Member's Recommendations			Model Status
Model Selection	1.	The consensus of the committee was that MODFLOW should be used.	1. As recommended by GWTAC. (See Section 3.1)
Model Construction			
Grid	1.	The consensus of the committee was that the grid should be oriented northwest-southeast, reflecting the major groundwater flow directions.	1. As recommended by GWTAC. (See Section 4.2)
	2.	The consensus of the committee was that the grid cells should be smallest in the center of the basin (where most of the pumping occurs).	2. As recommended by GWTAC. (See Section 4.2)
Layering	1.	The consensus of the committee was that the layering should reflect the three-dimensional aspect of groundwater flow in the confined zone. Layers should coincide with zones of apparent preferential groundwater flow (for example, where groundwater from the Santa Teresa Basin preferentially flows into the confined zone).	1. As recommended by GWTAC. The confined zone includes 3 separate layers. The single layer describing the Santa Teresa Basin is connected to the upper confined zone. (See Section 4.3.2)
Boundaries	1.	The consensus of the committee was that the model boundaries should be constant head at Coyote Narrows and constant head across San Francisco Bay.	1. As recommended by GWTAC. (See Section 4.4)
	2.	Two opinions were offered about the surface boundary: one opinion was to use a prescribed head surface; the second was to use a moveable water table boundary.	2. Surface boundary is a movable water table boundary. (See Section 4.4)
Parameterization	1.	The consensus of the committee was that the number of parameters must remain relatively small.	1. The GWTAC agreed the final model was modeled with adequately few parameters (21 parameters). (See Table 5.4)
	2.	Two parameterization options were discussed: one was to define parameter zones (and parameter values) for each of the layers to reflect the conceptual model. The second was to classify grain sizes from boreholes throughout the basin and assign parameter values at nodes based on weighted averages of these classifications.	2. The model includes parameter zones by layers that approximate the conceptual model. (See Section 4.5)

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Table A-1
Summary of GWTAC Recommendations

GWTAC Member's Recommendations			Model Status
Model Calibration	1.	The consensus of the committee was that calibration should be accomplished in stages: pre- and post-subsidence; pre development; and, under steady state and transient conditions.	1. As recommended by the GWTAC. (See Section 5.1)
	2.	Two opinions were offered about whether or not to set aside some of the data for verification runs. One opinion was that all data should be used to conduct a complete history match; and the second opinion was to retain some of the data for a verification period.	2. Data were set aside for a verification period. (See Section 5.1.1.3)
	3.	The consensus of the committee was that both hydrographs and head maps should be used during calibration.	3. As recommended by the GWTAC. (See Sections 5.1.4, 5.1.5, 5.1.6)
	4.	Consensus of the committee was that both manual and automatic inversing techniques should be used during calibration.	4. Only manual calibration was conducted. (See Section 5)
	5.	The consensus of the committee was that statistics should be used to help measure the calibration uncertainty.	5. As recommended by the GWTAC. (See Sections 5.1.6.4, 5.2, Appendix D, Appendix F)

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Appendix B
Specific Capacity Data

Well ID	Owner ID	Specific Capacity (gpm/ft)
05S3W35G10	PA-HALE	9.5
06S1W31B03	SNY-INDUS	28.6
06S1E33F10	SJMAB-2	19.1
06S1E33F06	SJMAB-1	31.8
06S1E31K01	SJGSH-2	90.0
06S1E31K02	SJGSH-1	111.1
06S1E17G04	SJFLE-4	20.4
06S1E17G06	SJFLE-3	14.8
06S1E17G05	SJFLE-2	43.8
06S1E16K04	SJCRO-4	23.8
06S1E16K05	SJCRO-3	31.8
06S1E16K10	SJCRO-2	38.5
06S1E16K03	SJCRO-1	22.9
06S1E30D11	SJBRE-2	91.1
06S1E30D10	SJBRE-1	62.5
06S1E32G01	SJBER-1	76.9
06S1W26D02	SCL-26	20.9
06S1W32H01	SCL-21	60.0
06S1W22B01	SCL-19	30.0
06S1W33N01	SCL-12	85.0
06S3W13A10	PA-MATADR	4.7
06S2W20L06	NLOSALTOS	4.2
06S2W34N03	CAL-6-02	27.1
06S2W28N01	CAL-4-02	5.0
06S2W34K02	CAL-17-01	57.7
06S2W29F02	CAL-16-01	4.2
07S1W07F01	SNY-WOLFE	4.5
07S2W11A01	SNY-SERRA	19.7
07S1W06R02	SNY-RAYNR	41.7
07S2W12A01	SNY-ORTGP	11.8
07S1E02J06	SJWSC-1	37.5
07S1E20Q05	SJWLG-5	72.7

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07S1E20Q04	SJWLG-4	333.3
07S1E20Q03	SJWLG-3	333.3
07S1E20Q02	SJWLG-2	56.2
07S1W22F01	SJWIL-9	58.9
07S1W22E06	SJWIL-8	49.0
07S1W22E05	SJWIL-7	46.7
07S1W22F02	SJWIL-6	84.3
07S1W22E04	SJWIL-5	67.9
07S1W22E03	SJWIL-4	76.9
07S1W22E02	SJWIL-3	300.0
07S1W22E01	SJWIL-2	75.0
07S1W22E08	SJWIL-16	51.1
07S1W22E09	SJWIL-15	45.3
07S1W22E10	SJWIL-14	40.1
07S1W22E11	SJWIL-13	67.0
07S1W22E13	SJWIL-11	60.9
07S1W22E14	SJWIL-10	61.9
07S1W34F05	SJVIR-5	8.1
07S1W34F04	SJVIR-4	7.9
07S1W34F03	SJVIR-3	4.7
07S1W34F01	SJVIR-2	8.5
07S1W34F02	SJVIR-1	10.5
07S1E22H07	SJTUL-4	55.6
07S1E22H06	SJTUL-3	100.0
07S1E22H05	SJTUL-2	61.3
07S1E22H04	SJTUL-1	88.9
07S1E02J00	SJSTO-2	9.5
07S1E02J06	SJSTO-1	33.2
07S1W27P81	SJSTM-3	53.8
07S1W17P01	SJSTE-2	5.7
07S1W20C01	SJSTE-1	11.8
07S1W26R04	SJRID-3	17.0
07S1W26R03	SJRID-2	32.0
07S1W26R02	SJRID-1	16.7
07S1E15N03	SJNEE-1	50.0
07S1W24J04	SJMER-4	33.3
07S1W24J05	SJMER-3	13.8
07S1W24J03	SJMER-2	35.1

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07S1W24J02	SJMER-1	87.5
07S1W33M02	SJMCC-2	5.4
07S1E29A02	SJMAL-2	58.8
07S1E29A01	SJMAL-1	150.0
07S1E07R08	SJMAI-T	84.8
07S1E07R07	SJMAI-S	147.5
07S1E18A01	SJMAI-R	120.0
07S1E07R05	SJMAI-Q	78.6
07S1E07R04	SJMAI-P	164.4
07S1E07R02	SJMAI-M	162.5
07S1E32G02	SJKOC-2	18.8
07S1E32G01	SJKOC-1	34.6
07S1E03A02	SJJAK-3	7.0
07S1E03A01	SJJAK-2	19.8
07S1E18P01	SJHOM-3	20.2
07S1E18Q01	SJHOM-2	16.7
07S1E18K03	SJHOM-1	24.1
07S1E17F01	SJGRA-1	41.3
07S1W20L03	SJDOY-3	2.7
07S1W20L02	SJDOY-2	3.9
07S1E18A02	SJDEL-2	214.3
07S1E18A03	SJDEL-1	100.0
07S1W31E03	SJCOX-2	2.0
07S1E21E06	SJCOT-7	79.2
07S1W13J04	SJBUV-9?	47.2
07S1W13J03	SJBUV-8	105.3
07S1W13K04	SJBUV-6	200.0
07S1W13J07	SJBUV-12	162.5
07S1W13J06	SJBUV-11	75.0
07S1W13J05	SJBUV-10	127.3
07S1W13E04	SJBAS-5	242.9
07S1E09D08	SJ-17-11	150.0
07S1W13E03	SJBAS-4	135.7
07S1W23R07	SJ3MI-7	15.4
07S1W23R06	SJ3MI-6	35.3
07S1W23R05	SJ3MI-5	57.1
07S1W23R04	SJ3MI-4	33.3
07S1W23R03	SJ3MI-3	46.2

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07S1W23R02	SJ3MI-2	91.5
07S1W23R01	SJ3MI-1	87.5
07S1E09D06	SJ-17-9	70.4
07S1E09D80	SJ-17-8	89.2
07S1E09D05	SJ-17-7	52.2
07S1E09D09	SJ-17-12	71.1
07S1W13E02	SJBAS-3	72.7
07S1E09D07	SJ-17-10	95.2
07S1E16C07	SJ-12-9	69.1
07S1E16C05	SJ-12-7	46.9
07S1E16C04	SJ-12-6	78.9
07S1E16F10	SJ-12-13	98.1
07S1E16G10	SJ-12-12	88.9
07S1E16C09	SJ-12-11	80.0
07S1E16C08	SJ-12-10	111.9
07S1E16C06	SJ-12-1	102.5
07S1W17A02	SCL-9-02	78.0
07S1W09N01	SCL-8	53.0
07S1W04E03	SCL-7?	49.8
07S1W04E02	SCL-7	69.0
07S1W15D01	SCL-6	165.0
07S1W02B01	SCL-5-02	49.0
07S1W03Q01	SCL-4	97.0
07S1W03H02	SCL-30	200.0
07S1W02G02	SCL-3	67.0
07S1W09N02	SCL-29	139.8
07S1W10D10	SCL-28	284.0
07S1W04Q01	SCL-25	66.7
07S1W05P02	SCL-24	97.0
07S1W09Q01	SCL-23	92.3
07S1W11D02	SCL-2-02	93.5
07S1W08B02	SCL-17-02	87.0
07S1W08B01	SCL-17	12.9
07S1W02A10	SCL-16-02	68.0
07S1W04D01	SCL-14	43.0
07S1W02P03	SCL-13-02	75.0
07S1W09J01	SCL-11	241.0
07S1W15E01	SCL-10	165.7

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07S1W02G03	SCL-1-02	70.6
07S2W12F01	CUP-HOM3	17.2
07S1E26B02	CSJ-EV3	87.5
07S1E26B11	CSJ-5	31.3
07S1W08K01	CAL-29-01	10.0
07S2W13C01	CAL-24-01	5.0
07S1W06P01	CAL-20-01	85.7
08S1E06H01	SJWLM-1	4.3
08S1W03H01	SJPAR-1	0.5
08S1E05H07	SJBRY-5	15.6
08S1E05H06	SJBRY-4	10.3
08S1E05H05	SJBRY-3	14.3
08S1E05H04	SJBRY-2	10.4
08S1E05H03	SJBRY-1	11.4
08S1E04M04	SJBRA-4	4.5
08S1E04M03	SJBRA-3	36.6
08S1E04M02	SJBRA-2	31.0
08S1E04M01	SJBRA-1	11.2
08S1E10G05	SJBLO-6	12.5
08S1E10G03	SJBLO-4	58.8
08S1E10G02	SJBLO-3	22.0
08S1E10K04	SJBLO-2	6.5
08S1E10K03	SJBLO-1	133.3
08S2E06M10	GO-9	40.5
08S2E17J10	GO-7	43.1
08S1E13H10	GO-3	226.4
08S1E12P01	GO-2?	135.0
08S2E08Q01	GO-18	24.1
08S2E17G11	GO-16	49.2
08S2E08M07	GO-15	83.2
08S2E18E11	GO-12	57.8
08S1E01J02	GO-1	187.0

Source: CH2M HILL, 1992a.

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Appendix C

Potential and Selected Calibration Wells

List of 343 wells without substantial pumping.

05S1E31E01 05S2W32F10 06S1E05P01 06S1E05Q02 06S1E06B03 06S1E06N01
06S1E06P02 06S1E07E01 06S1E15Q01 06S1E16H01 06S1E16K03 06S1E17M01
06S1E17Q01 06S1E17Q02 06S1E18K01 06S1E18L01 06S1E20N04 06S1E20Q02
06S1E21H01 06S1E21M04 06S1E21M06 06S1E22R01 06S1E23M01 06S1E23P01
06S1E26G01 06S1E26G03 06S1E27B01 06S1E27B02 06S1E27E01 06S1E27M02
06S1E27N02 06S1E27P02 06S1E27Q02 06S1E28H03 06S1E29B05 06S1E29G06
06S1E30R01 06S1E31A02 06S1E31M02 06S1E32H04 06S1E32M05 06S1E32R01
06S1E34B02 06S1E34D02 06S1E34F02 06S1E34K01 06S1E34M01 06S1E35M01
06S1W01K01 06S1W05L01 06S1W05L02 06S1W05L03 06S1W10M01 06S1W11N03
06S1W12M02 06S1W12R01 06S1W12R01 06S1W14C01 06S1W14L04 06S1W16N02
06S1W16N03 06S1W19B01 06S1W21J01 06S1W21R04 06S1W22C01 06S1W22H01
06S1W22N01 06S1W23K01 06S1W23Q01 06S1W24B04 06S1W24H04 06S1W24K02
06S1W24N01 06S1W25E05 06S1W26F03 06S1W27K01 06S1W28F01 06S1W28R01
06S1W29C01 06S1W29Q02 06S1W31E01 06S1W31E02 06S1W32L04 06S1W32M02
06S1W35K01 06S1W35L01 06S2W03N01 06S2W05F01 06S2W05F02 06S2W05F03
06S2W07L10 06S2W08H01 06S2W09N11 06S2W10G02 06S2W13F01 06S2W15M09
06S2W16C18 06S2W16E04 06S2W17P01 06S2W18J01 06S2W18R01 06S2W19G01
06S2W20L01 06S2W21A01 06S2W22E02 06S2W22H04 06S2W22H05 06S2W22M01
06S2W23Q02 06S2W24C03 06S2W24M01 06S2W25C02 06S2W26R01 06S2W27B01
06S2W28K01 06S2W29M01 06S2W32D02 06S2W33A02 06S2W33H01 06S3W34B02
06S2W34B03 06S2W35C01 06S2W35H02 06S2W36J01 06S3W01D10 06S3W01M10
06S3W02J10 06S3W12C10 06S3W12R10 06S3W13A10 07S1E01N01 07S1E02J01
07S1E02J06 07S1E03A02 07S1E03H01 07S1E03L01 07S1E06L01 07S1E06M01
07S1E06N02 07S1E07F01 07S1E07R01 07S1E07R05 07S1E08M01 07S1E09D03
07S1E09D06 07S1E10P01 07S1E12M03 07S1E13D01 07S1E14P01 07S1E14P01
07S1E15C03 07S1E15D05 07S1E15E02 07S1E1SF01 07S1E15L04 07S1E16C05
07S1E16C06 07S1E18C02 07S1E21A02 07S1E21E02 07S1E21E03 07S1E22K01
07S1E22N02 07S1E23B01 07S1E23D01 07S1E23E01 07S1E23F04 07S1E23K01
07S1E24C01 07S1E24F02 07S1E24G02 07S1E24M02 07S1E25A02 07S1E25A03
07S1E25M03 07S1E25M04 07S1E25M06 07S1E26R01 07S1E27F03 07S1E27G03
07S1E30B04 07S1E30P01 07S1E31A01 07S1E31A03 07S1E32G01 07S1E33M03
07S1E35E01 07S1E36G01 07S1W02G01 07S1W03G02 07S1W05L01 07S1W05R02
07S1W06D01 07S1W07K01 07S1W09E02 07S1W10D01 07S1W11E01 07S1W13E01
07S1W13J07 07S1W13K04 07S1W14N01 07S1W17B01 07S1W17E01 07S1W17P01
07S1W18N02 07S1W18R01 07S1W19H02 07S1W20C01 07S1W21A01 07S1W21P01
07S1W22E02 07S1W22E06 07S1W22E09 07S1W22E14 07S1W23R01 07S1W24A01
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07S2E19E02 07S2E19J01 07S2E20E05 07S2E20H02 07S2E20R01 07S2E28F01
07S2E29B01 07S2E33C01 07S2E33C03 07S2E33C04 07S2W01Q01 07S2W04G01
07S2W09A01 07S2W12C01 07S2W12M01 07S2W14G01 07S2W14H02 07S2W15M10
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```
08S1E02R01  08S1E04A05  08S1E04D01  08S1E04F01  08S1E04L03  08S1E04P01
08S1E04Q05  08S1E05D01  08S1E05F02  08S1E05N01  08S1E07A01  08S1E07G02
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08S1E13L01  08S1Q13Q01  08S1E14B01  08S1E14D02  08S1E14D04  08S1E15C02
08S1E15E02  08S1E17B03  08S1E17R02  08S1E27C02  08S1W03K01  08S1W03K02
08S1W03K03  08S1W05A01  08S1W05K04  08S1W08J05  08S1W11H01  08S1W11R01
08S1W12Q02  08S1W13A01  08S1W15B01  08S1W15C01  08S2E07A03  08S2E08K01
08S2E08R01  08S2E17J01  08S2E17N01  08S2E18L01  08S2E19A01  08S2E22F01
08S2E26M02  08S2E27G01  08S2E28H03  08S2E31Q01  08S2E34A01  08S2E35G01
08S2E35M01  08S2E35M01  08S2W01C01  07S1E07R99  07S1W02G02  06S1W24H08
06S2W24C07
```

From the previous list, 117 wells with sufficient well completion information for calibration purposes.

```
05S2W32F10  06S1E06NO1  06S1E34B02  06S1W12M02  06S1W28FO1  06S2W05FO1
06S2WOSF03  06S2W08HO1  07S1E07R05  07S1E1OPO1  07S1E22N02  07S1E23DO1
07S1E23EO1  07S1E23F04  07S1E24G02  07S1E25A03  07S1E25M04  07S1E27F03
07S1E33M03  07S1E35EO1  07S1W07KO1  08S1E02C02  08S1E02RO1  08S1E04A05
08S1EOSDO1  08S1EOSNO1  08S1E07G02  08S1E08HO1  08S1E1OJO1  08S1E11QO1
08S1E12CO1  08S1E14D02  08S1E1SC02  08S1E27C02  08S1W11RO1  08S1W12Q02
08S1W1SCO1  08S2E07A03  08S2E08RO1  08S2E17NO1  08S2E18LO1  06S1W1OMO1
06S1W21JO1  06S1W22HO1  06S1W23KO1  06S1W35KO1  06S2W33A02  06S3WO1M10
06S3W13A10  07S1E13DO1  07S1E31AO1  07S2W12MO1  07S1W06PO1  06S1WOSL03
06S1W21JO1  06S1W31EO1  06S2W03NO1  06S2W1OG02  06S2W13FO1  06S2W21AO1
06S2W22H04  06S2W22MO1  06S2W23Q02  06S2W26RO1  07S1WQ2GO1  07S1W09E02
07S1W1ODO1  07S1W13EO1  07S1W13J07  07S1W13K04  07S1W17EO1  07S1W20CO1
07S1W21AO1  07S1W22E02  07S1W22E06  07S1W22E09  07S1W22E14  07S1W23RO1
07S1W24AO1  07S1W24E02  07S1W24H02  07S1W25LO1  07S1W28RO1  07S1W30CO1
07S1W33LO1  07S1W35HO1  07S1W36BO1  06S1E16K03  06S1E17MO1  06S1E17QO1
06S1E18KO1  06S1E20N04  06S1E20Q02  06S1E21M04  06S1E27EO1  06S1E27M02
06S1E27P02  06S1E27Q02  06S1E29G06  06S1E30RO1  06S1E31A02  06S1E32M05
06S1E32RO1  06S1W24H04  06S1W24K02  07S1EO1NO1  07S1E02J06  07S1E03HO1
07S1E06LO1  07S1E06MO1  07S1E06N02  07S1E07FO1  07S1E09D03  07S1E09D06
06S2W25C02 07S1E16C06 08S1W03K03
```

Appendix D
Scattergrams of Simulated and Measured Water Levels

Scattergrams for individual wells display the correlation between simulated and measured water levels. Simulated water levels from the end of the second and fourth quarter of each year were compared to water levels collected within 2 weeks on either side of June 30 and December 31.

Each open circle on the scattergrams represents one data point comparing a simulated and measured water level. Scattergrams have different numbers of data points because measured water levels that met the time window criteria were often not available.

The solid line bisecting each graph is the theoretical "exact match" line where simulated water levels equal measured water levels. Each data point would fall on this line if simulated water levels exactly matched measured water levels. Three lines parallel each side of the theoretical "exact match" line, corresponding to the three calibration criteria proposed by the SCVWD. The dashed lines nearest the "exact match" line envelop all data points with simulated water levels no more than 5 feet different from the measured water level. The second set of dashed lines envelop data points with up to 10 feet of error, and the third set of dashed lines envelop data points with up to 20 feet of error.

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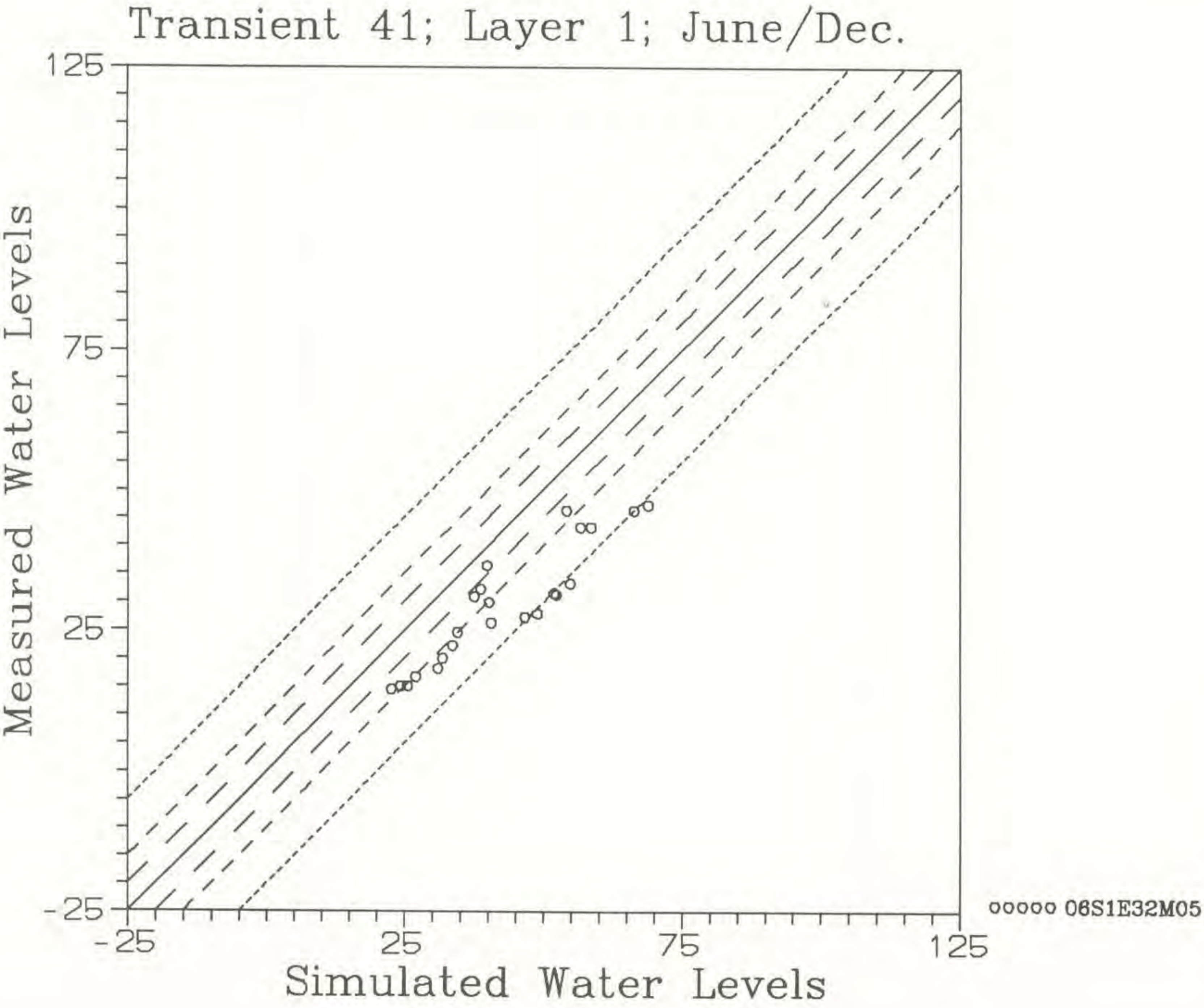
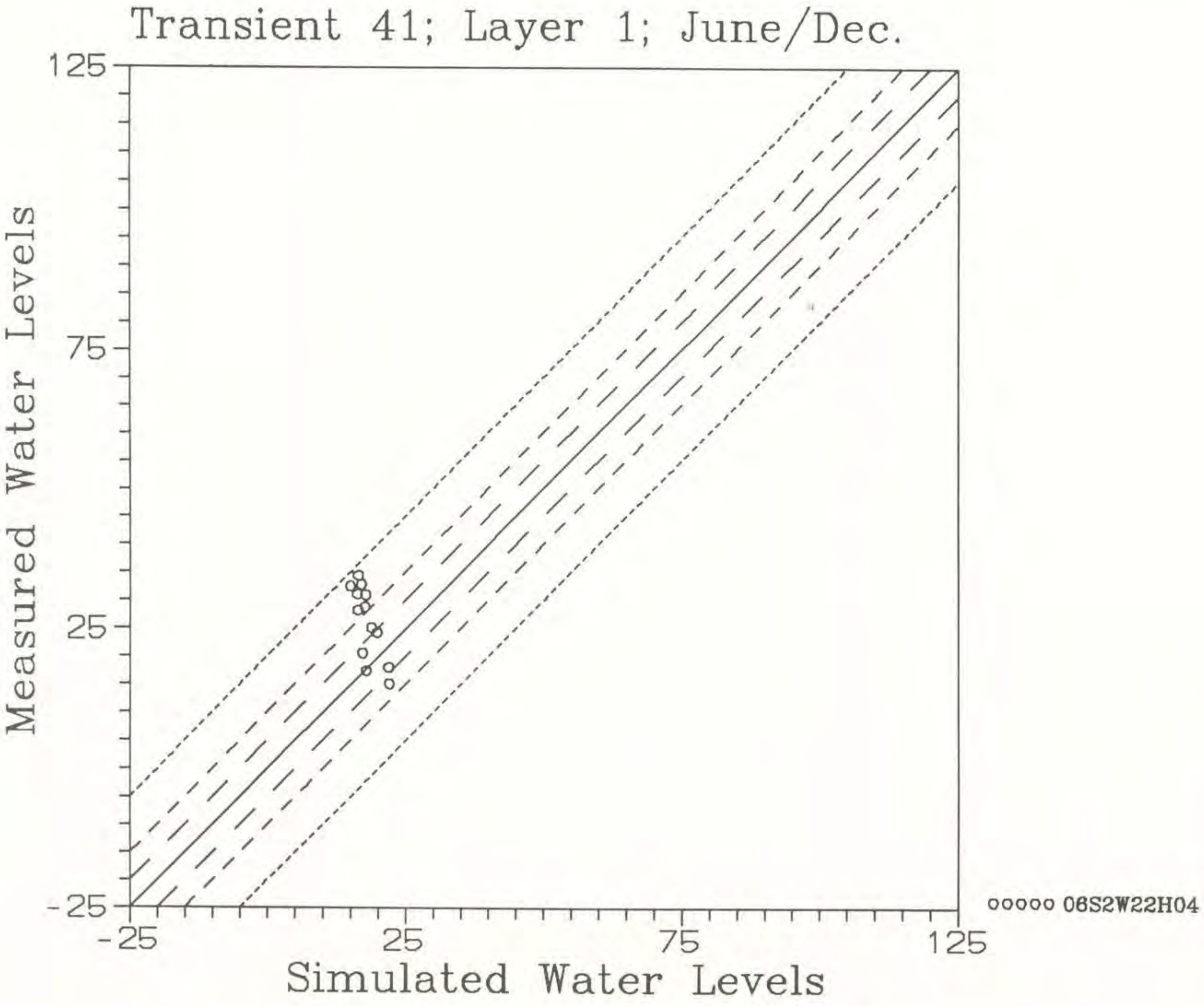
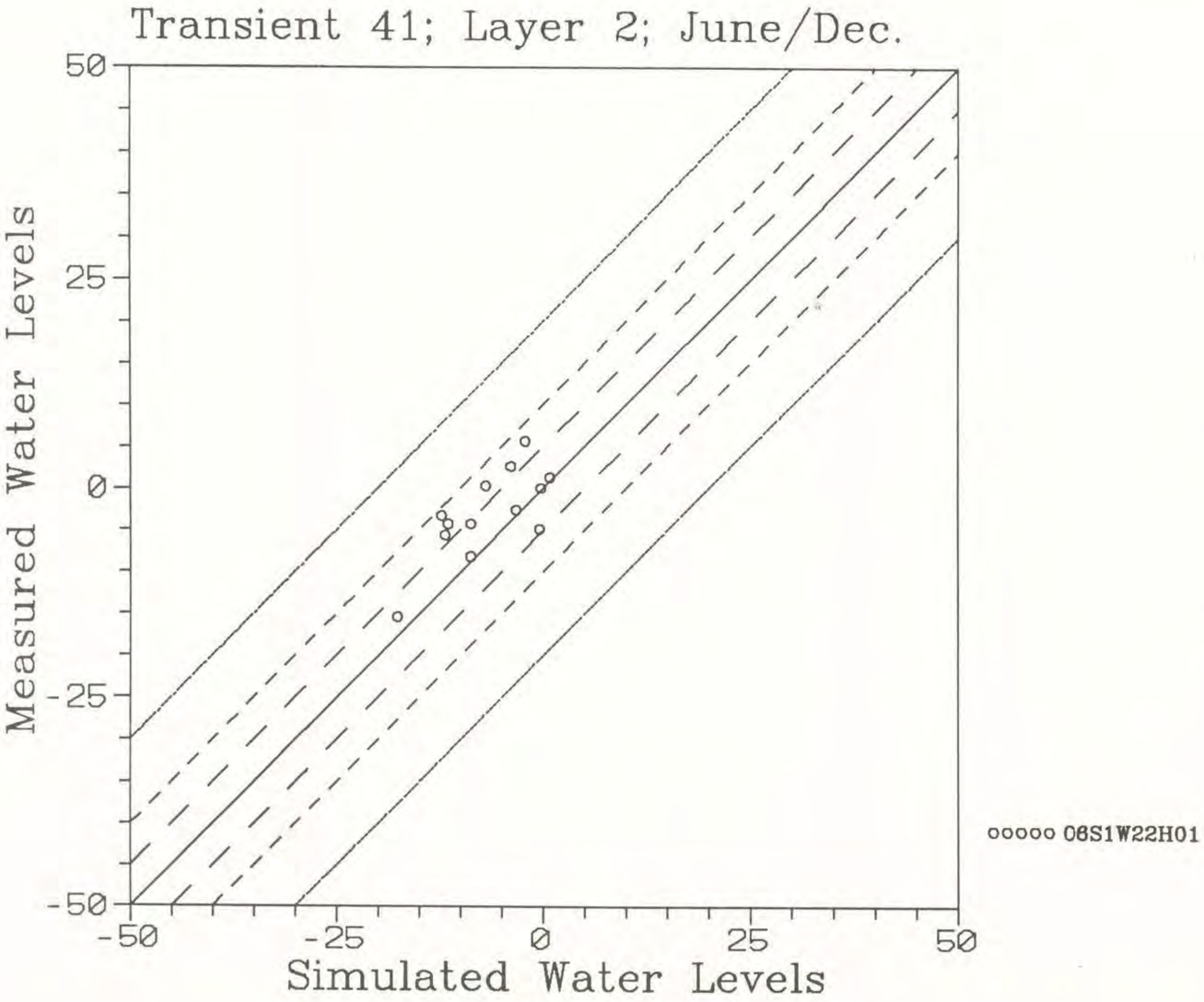
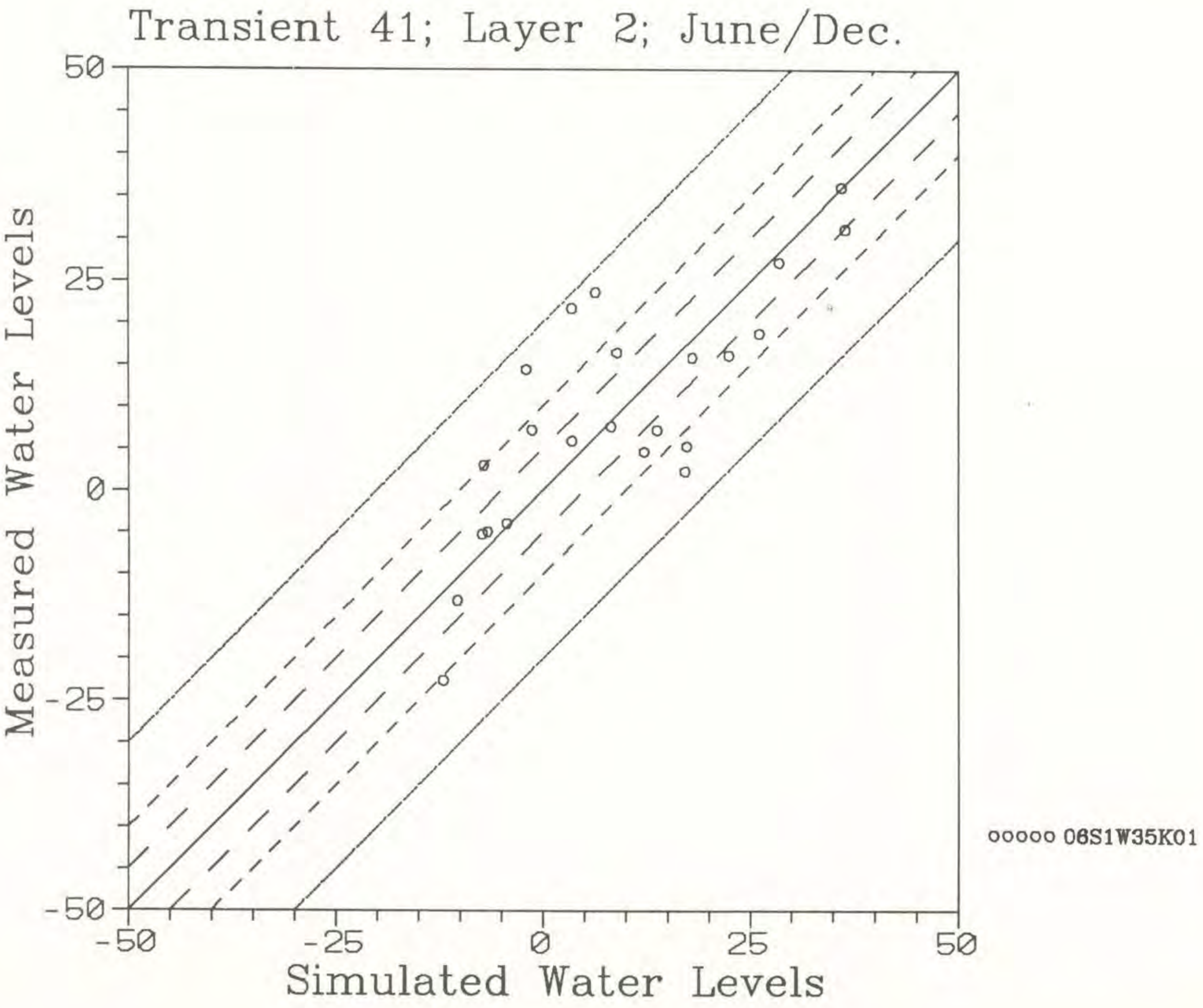


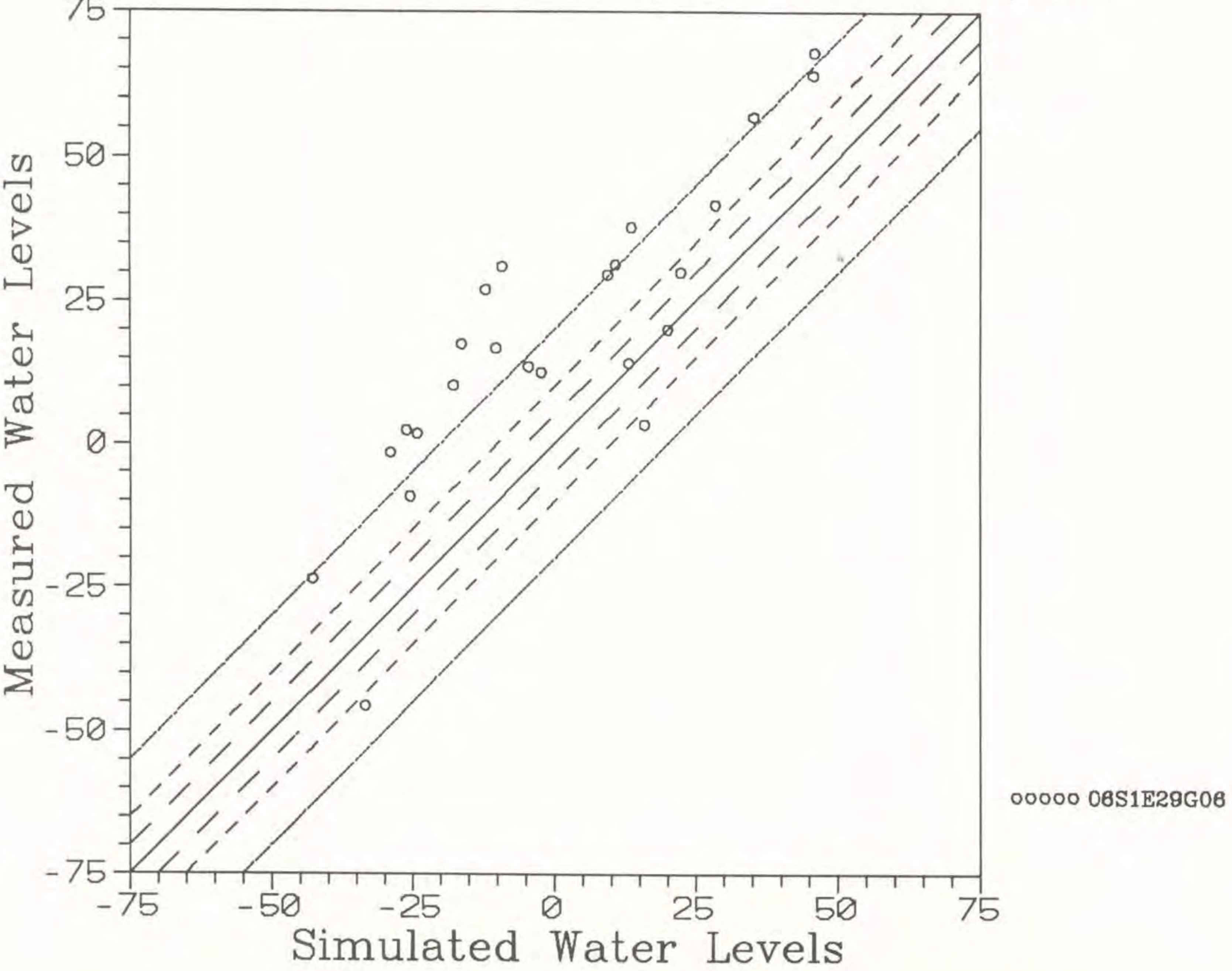
Transient 41; Layer 1; June/Dec.

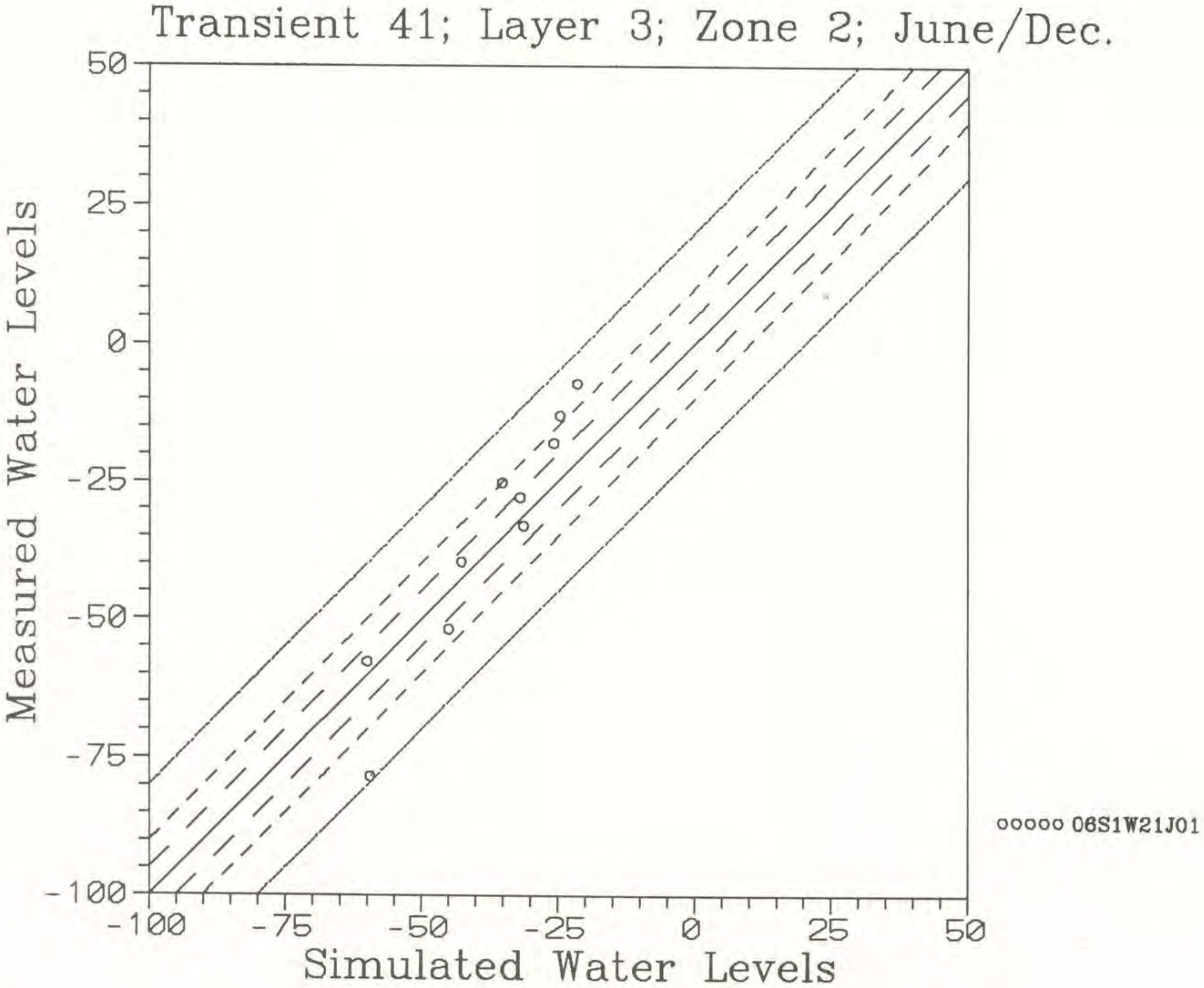

Transient 41; Layer 1; June/Dec.
125
75
25
-25
Measured Water Levels
-25
25
75
125
Simulated Water Levels
ooooo 06S2W22H04

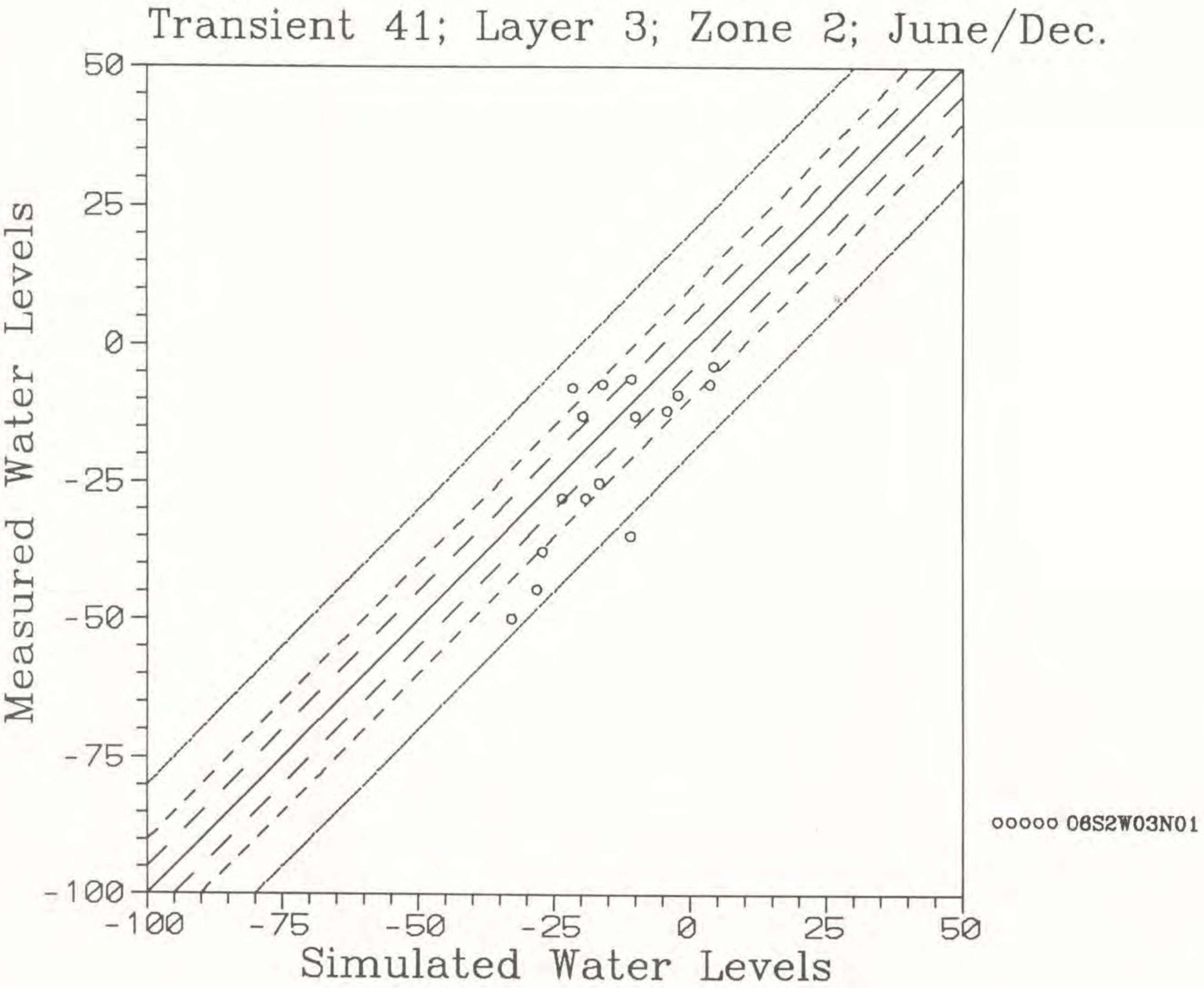

Transient 41; Layer 2; June/Dec.
Measured Water Levels
50
25
0
-25
-50
Simulated Water Levels
-50
-25
0
25
50
ooooo 06S1W22H01

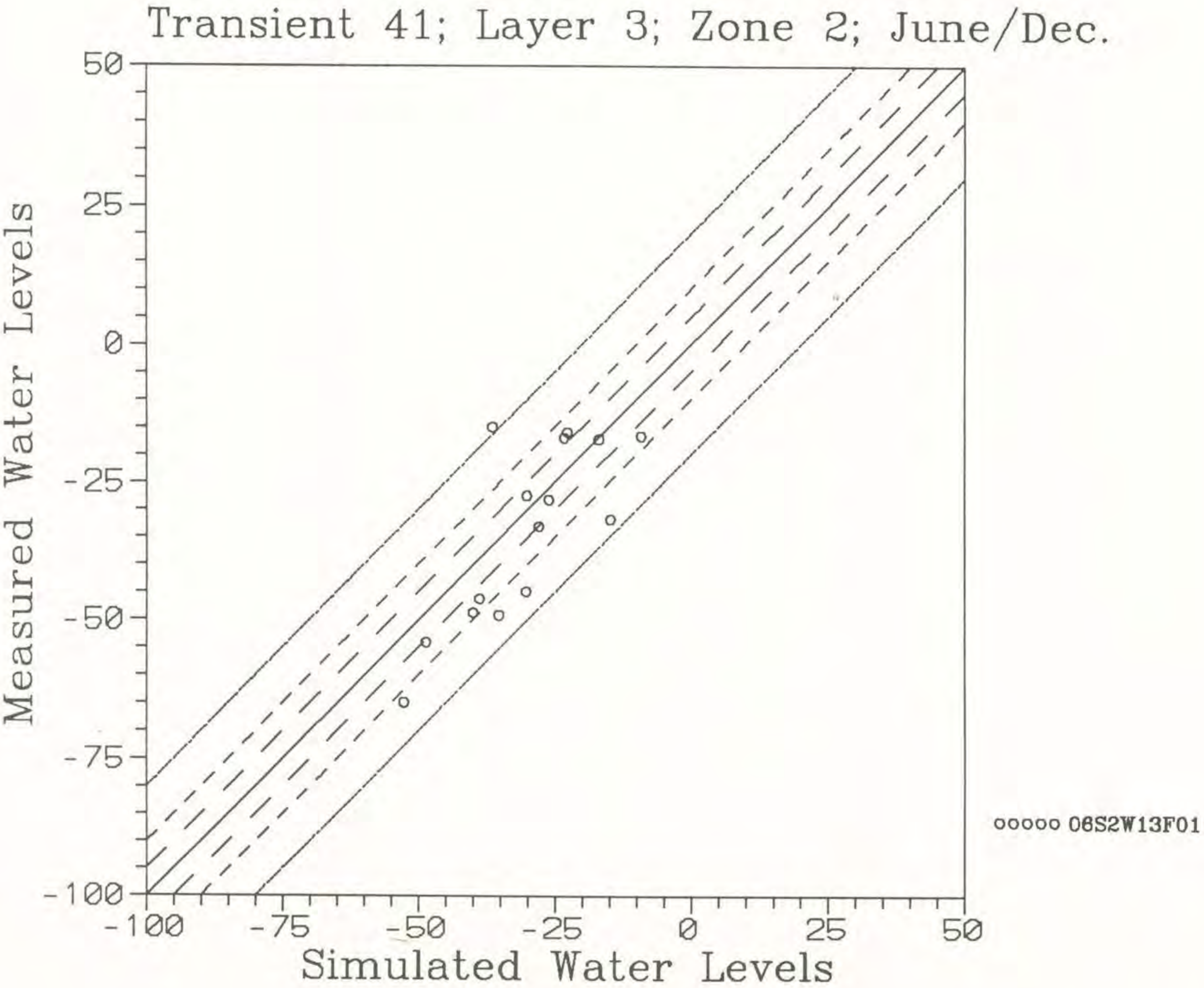

Transient 41; Layer 2; June/Dec.
Measured Water Levels
50
25
0
-25
-50
-50
-25
0
25
50
Simulated Water Levels
ooooo 06S1W35K01

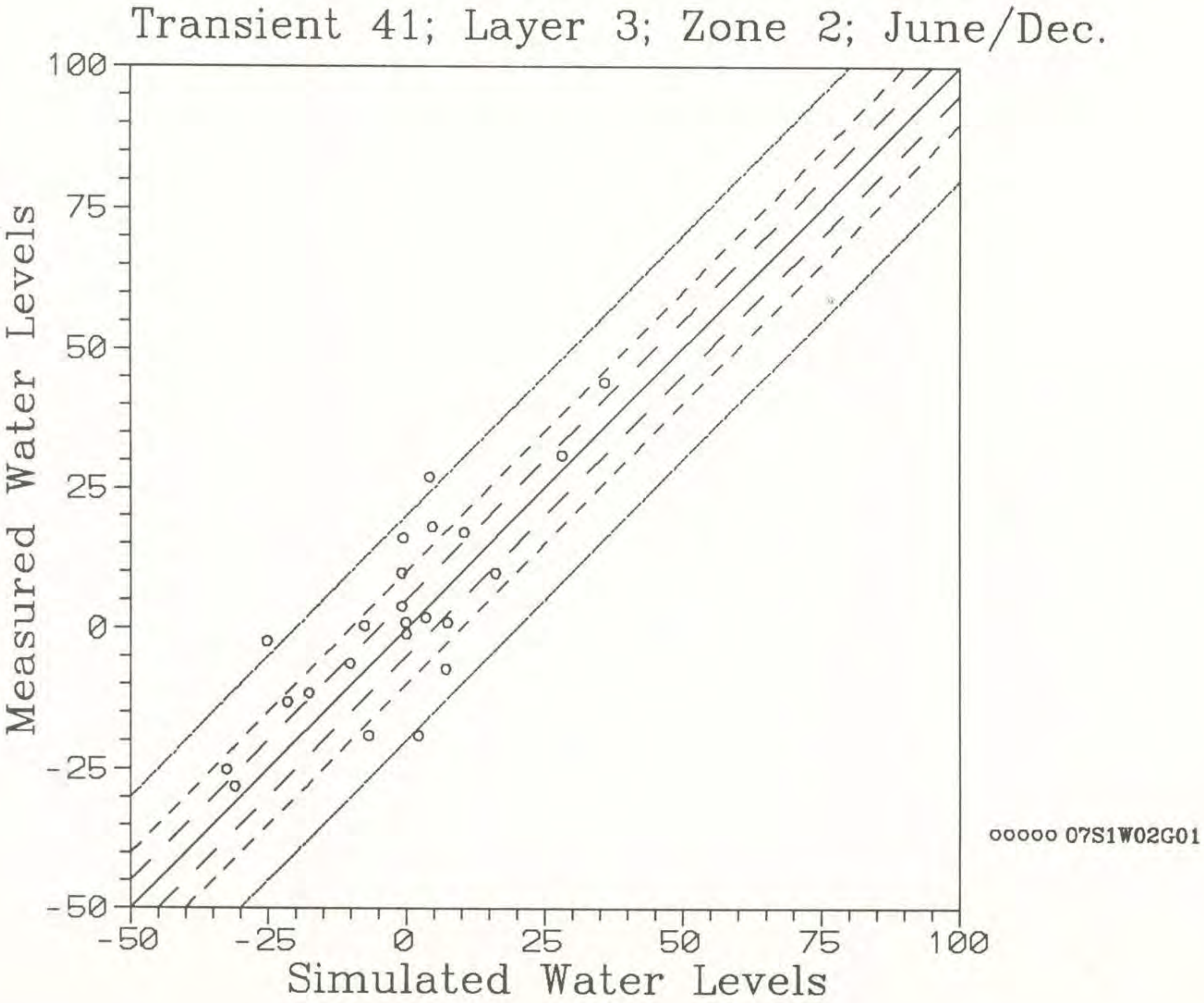
Transient 41; Layer 3; Zone 1; June/Dec.

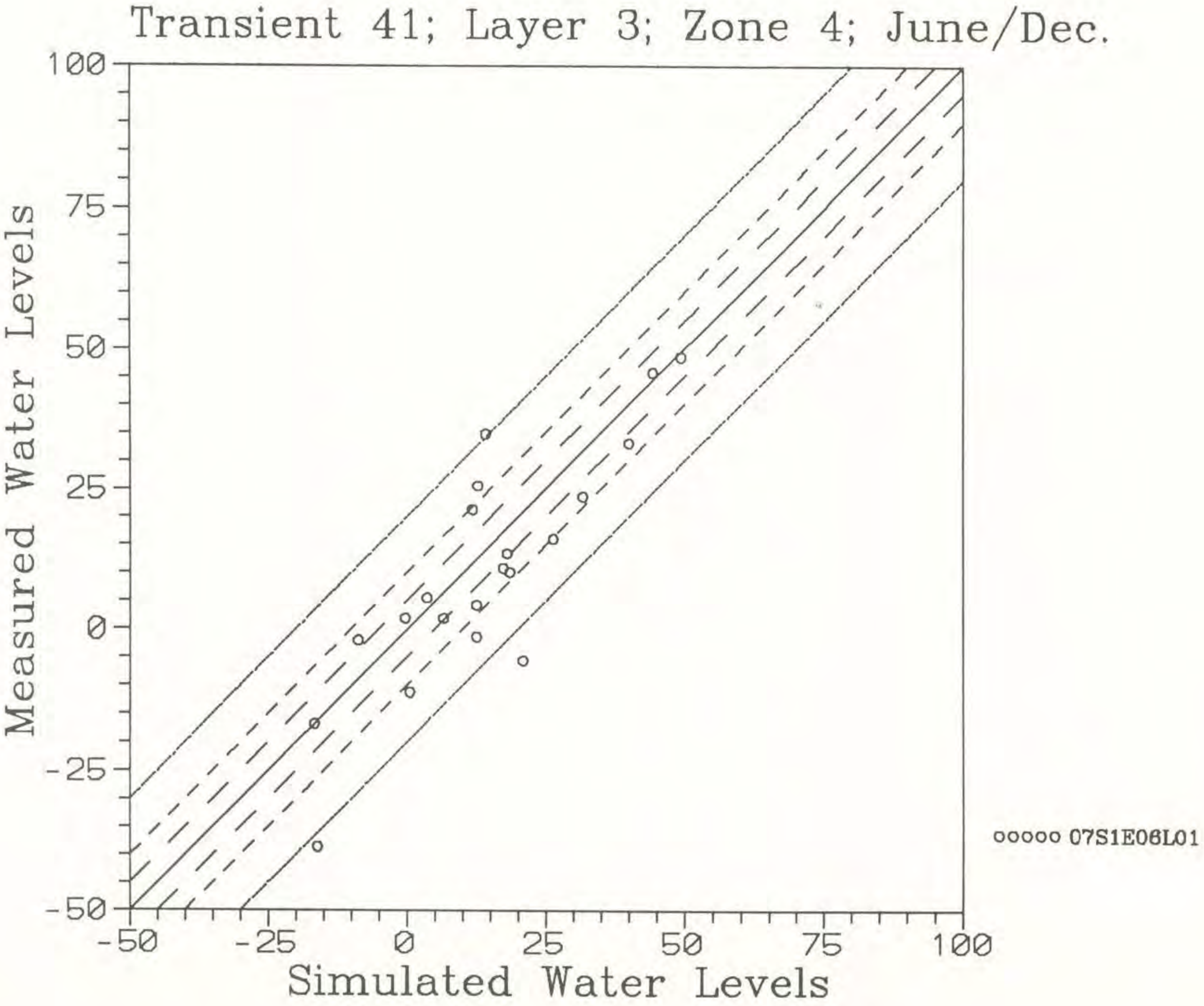


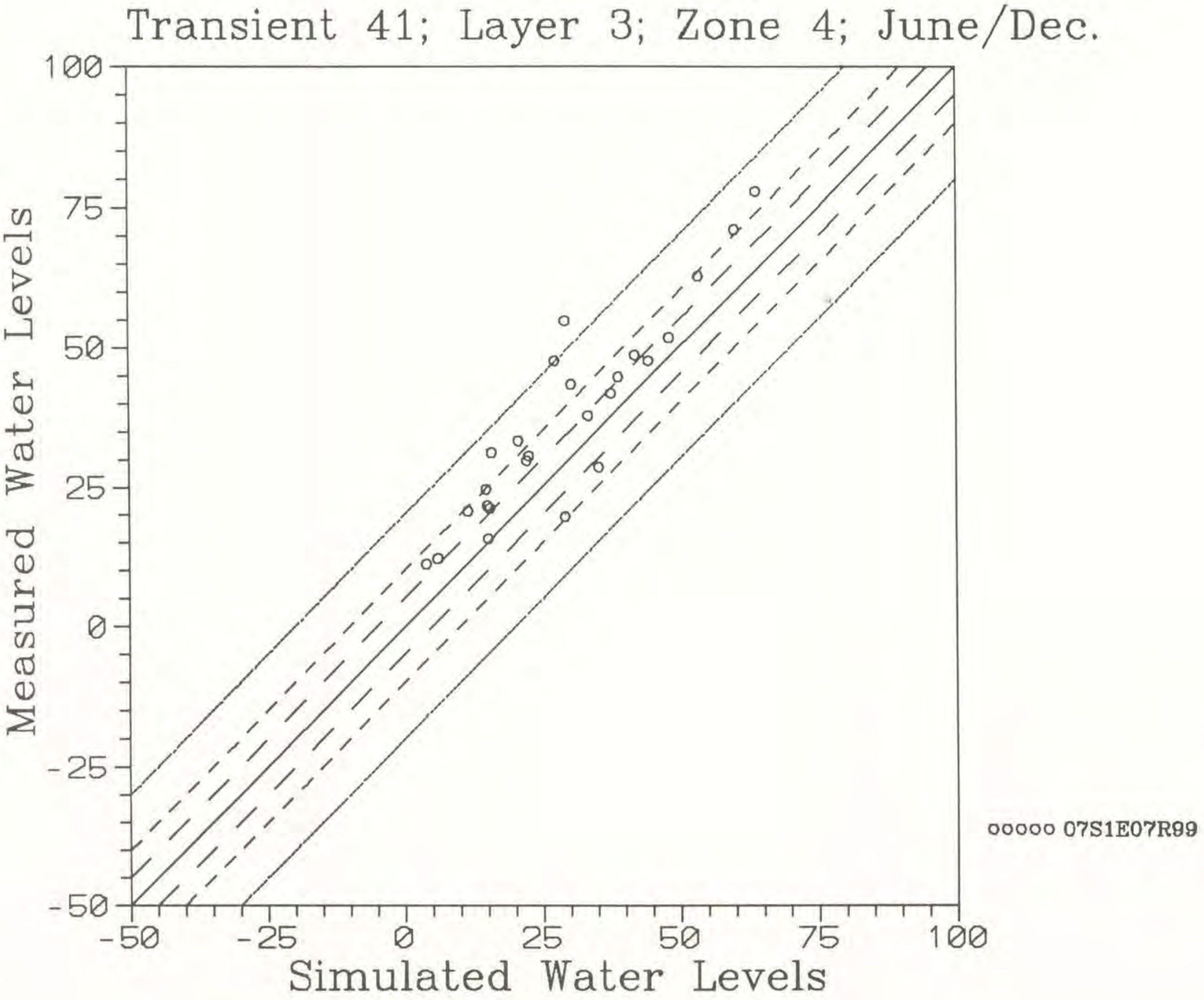

Transient 41; Layer 3; Zone 2; June/Dec.
Measured Water Levels
50
25
0
-25
-50
-75
-100
Simulated Water Levels
-100
-75
-50
-25
0
25
50
ooooo 06S1W21J01


Transient 41; Layer 3; Zone 2; June/Dec.
Measured Water Levels
Simulated Water Levels
50
25
0
-25
-50
-75
-100
-100
-75
-50
-25
0
25
50
ooooo 06S2W03N01

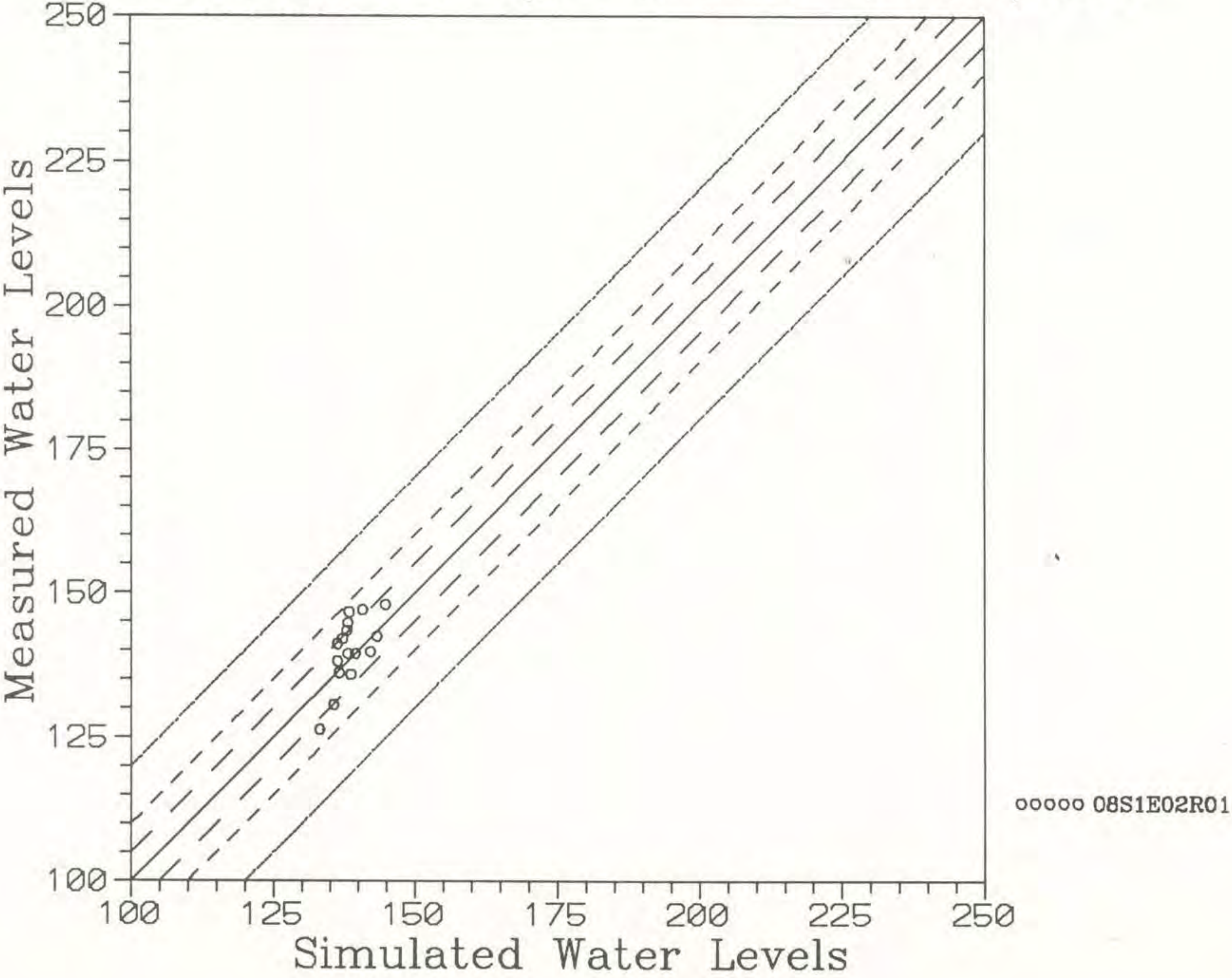

Transient 41; Layer 3; Zone 2; June/Dec.
Measured Water Levels
50
25
0
-25
-50
-75
-100
-100
-75
-50
-25
0
25
50
Simulated Water Levels
ooooo 06S2W13F01

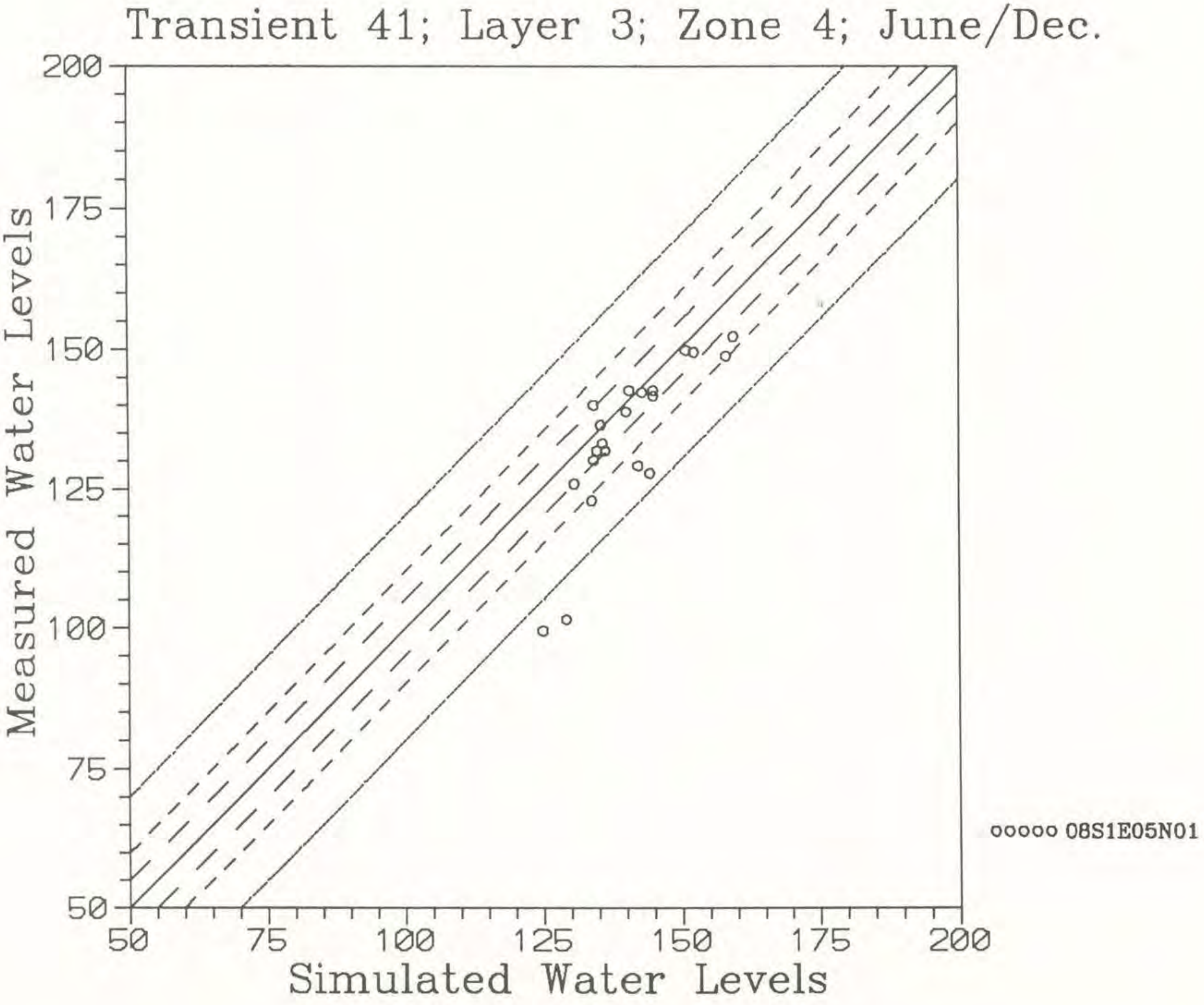

Transient 41; Layer 3; Zone 2; June/Dec.
100
75
50
25
0
-25
-50
Measured Water Levels
-50
-25
0
25
50
75
100
Simulated Water Levels
ooooo 07S1W02G01


Transient 41; Layer 3; Zone 4; June/Dec.
Measured Water Levels
Simulated Water Levels
100
75
50
25
0
-25
-50
-50
-25
0
25
50
75
100
ooooo 07S1E06L01


Transient 41; Layer 3; Zone 4; June/Dec.
Measured Water Levels
100
75
50
25
0
-25
-50
-50
-25
0
25
50
75
100
Simulated Water Levels
ooooo 07S1E07R99

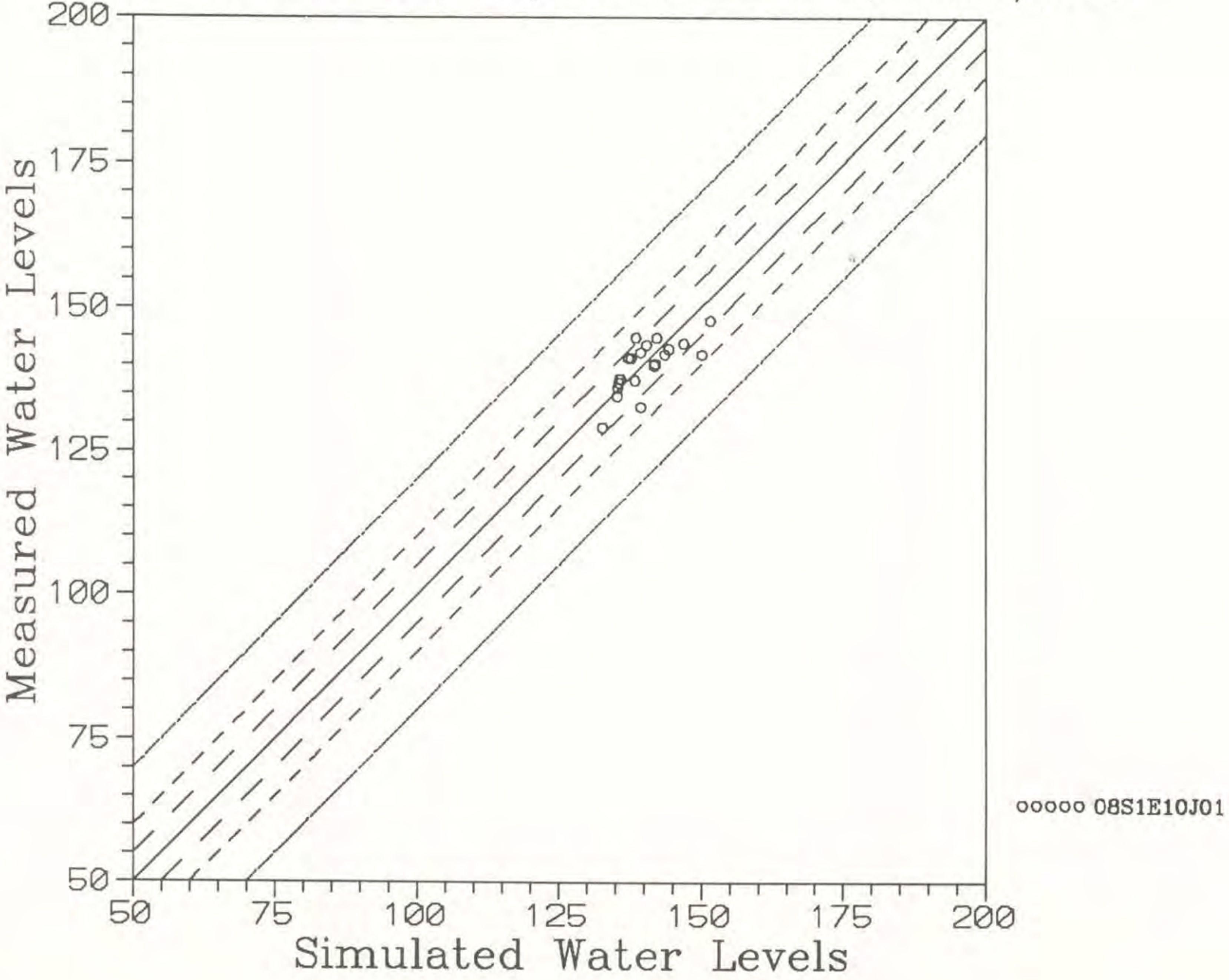
Transient 41; Layer 3; Zone 4; June/Dec.

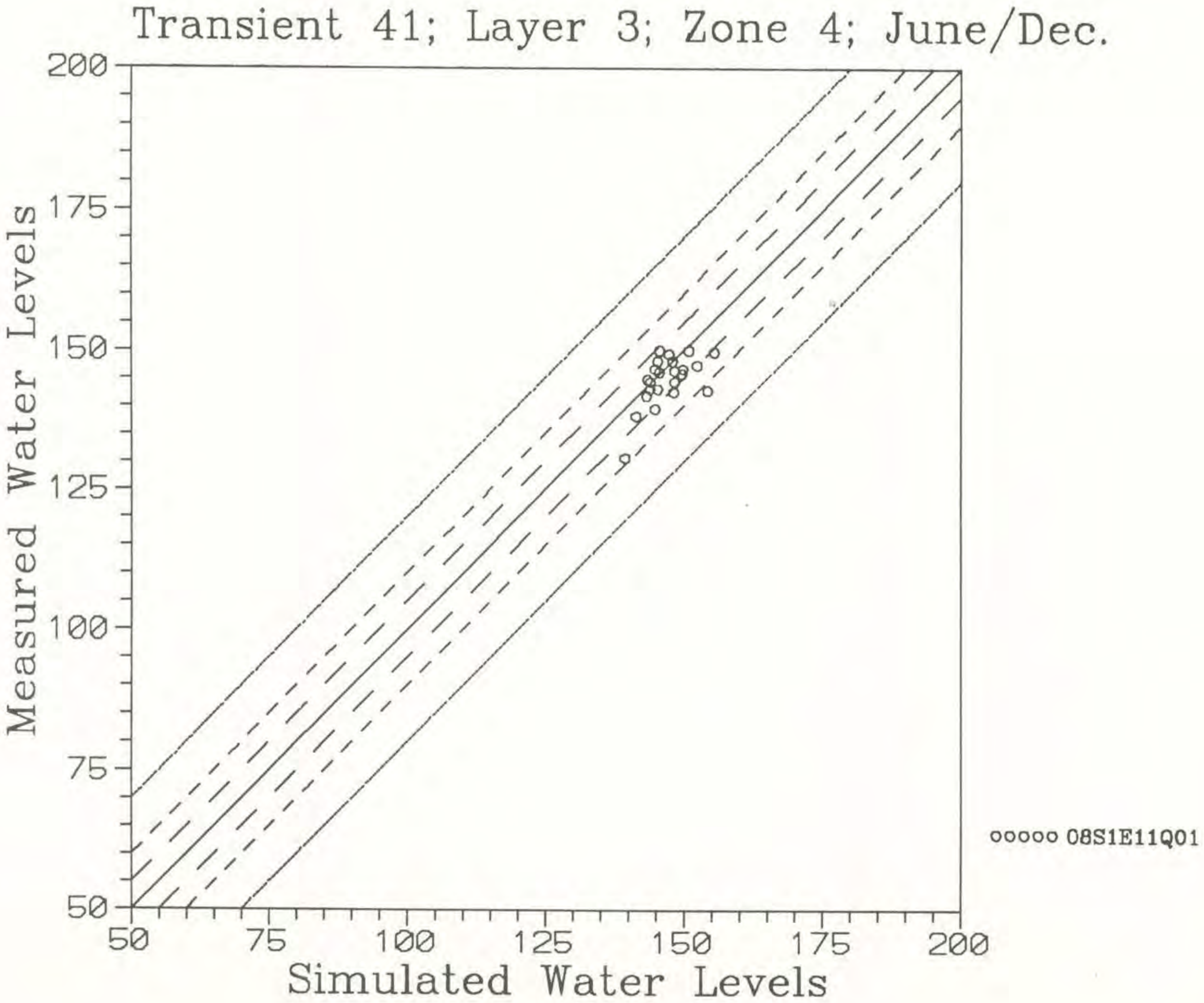


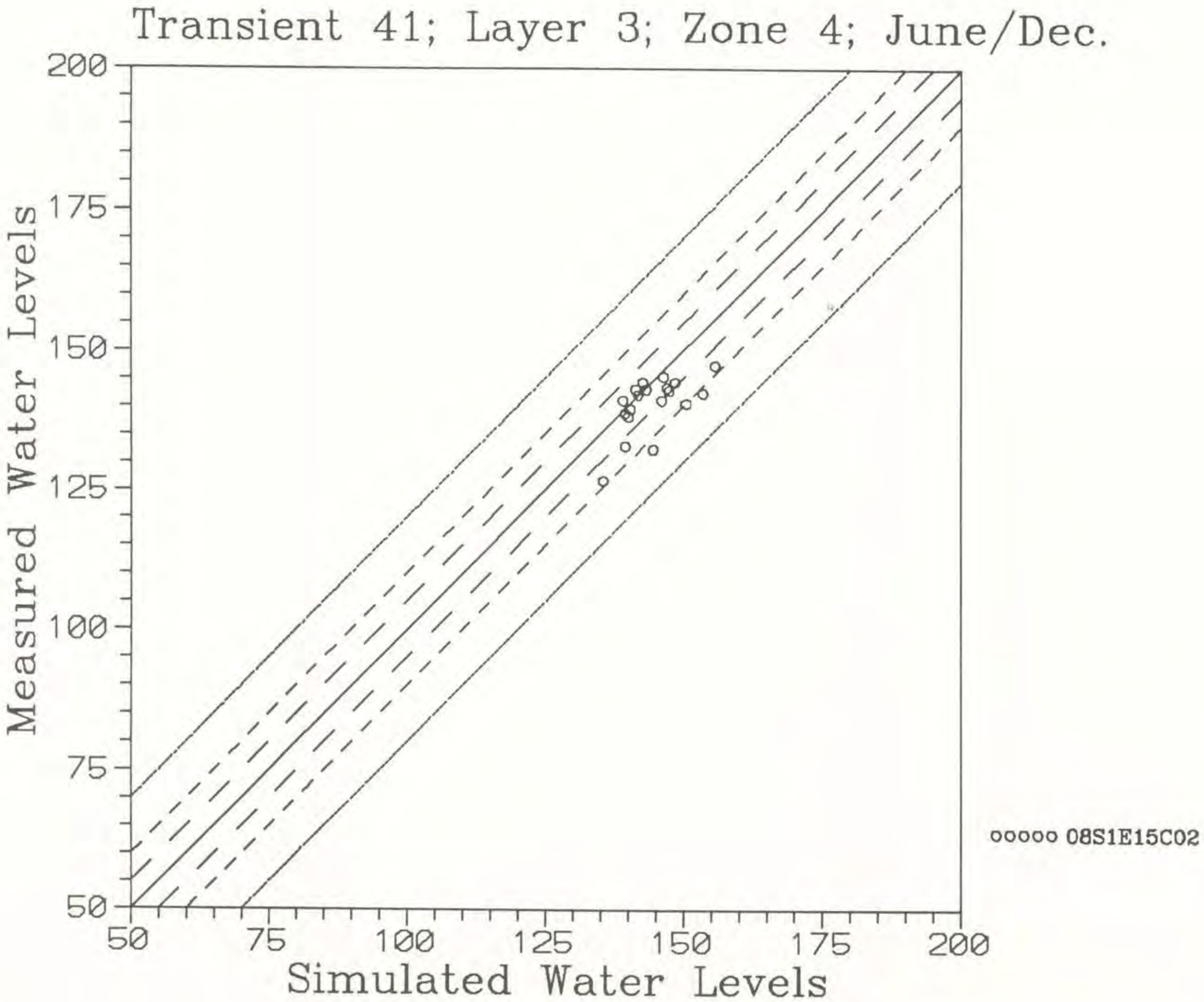


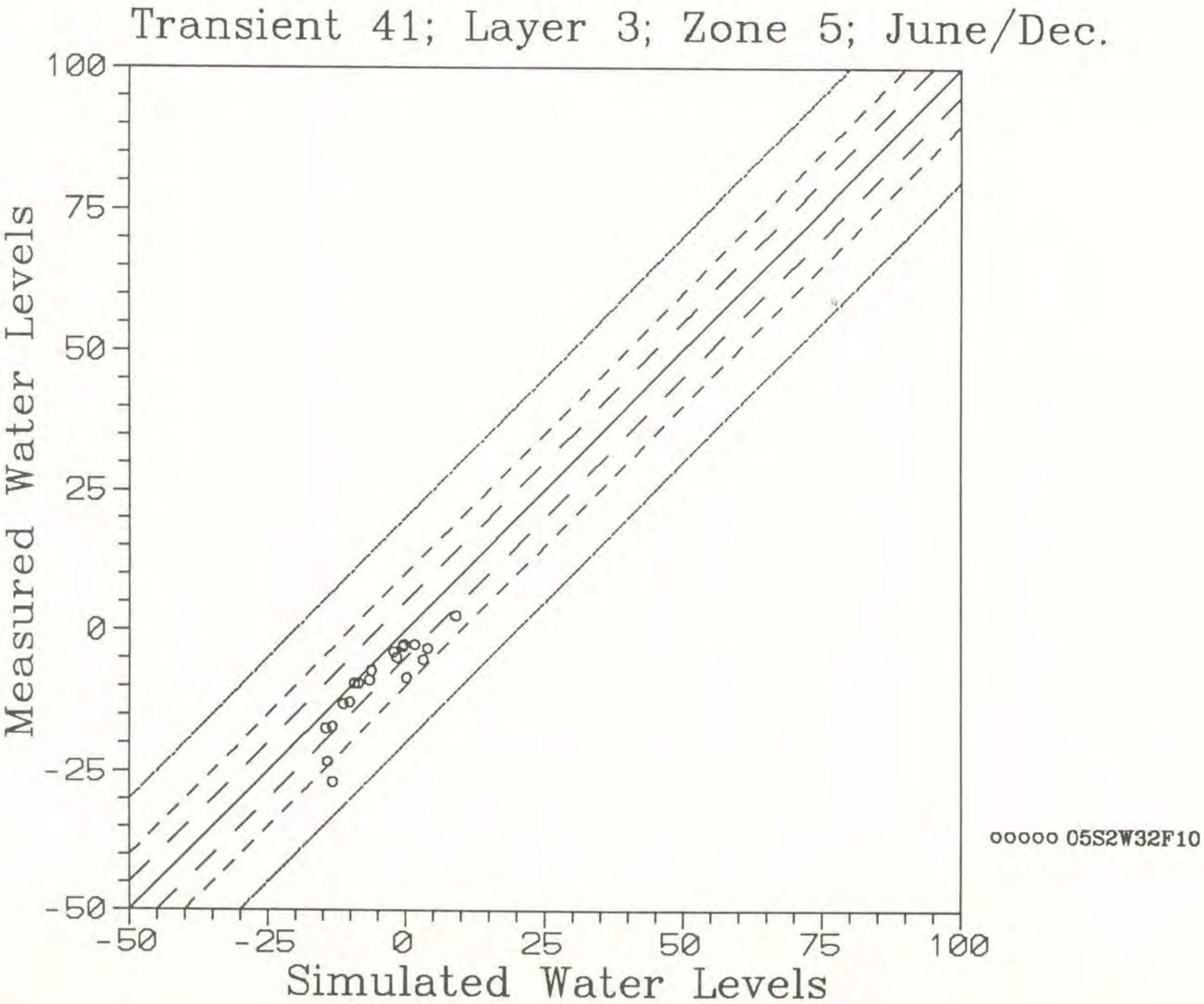
Transient 41; Layer 3; Zone 4; June/Dec.
Measured Water Levels
Simulated Water Levels
200
175
150
125
100
75
50
50
75
100
125
150
175
200
ooooo 08S1E05N01

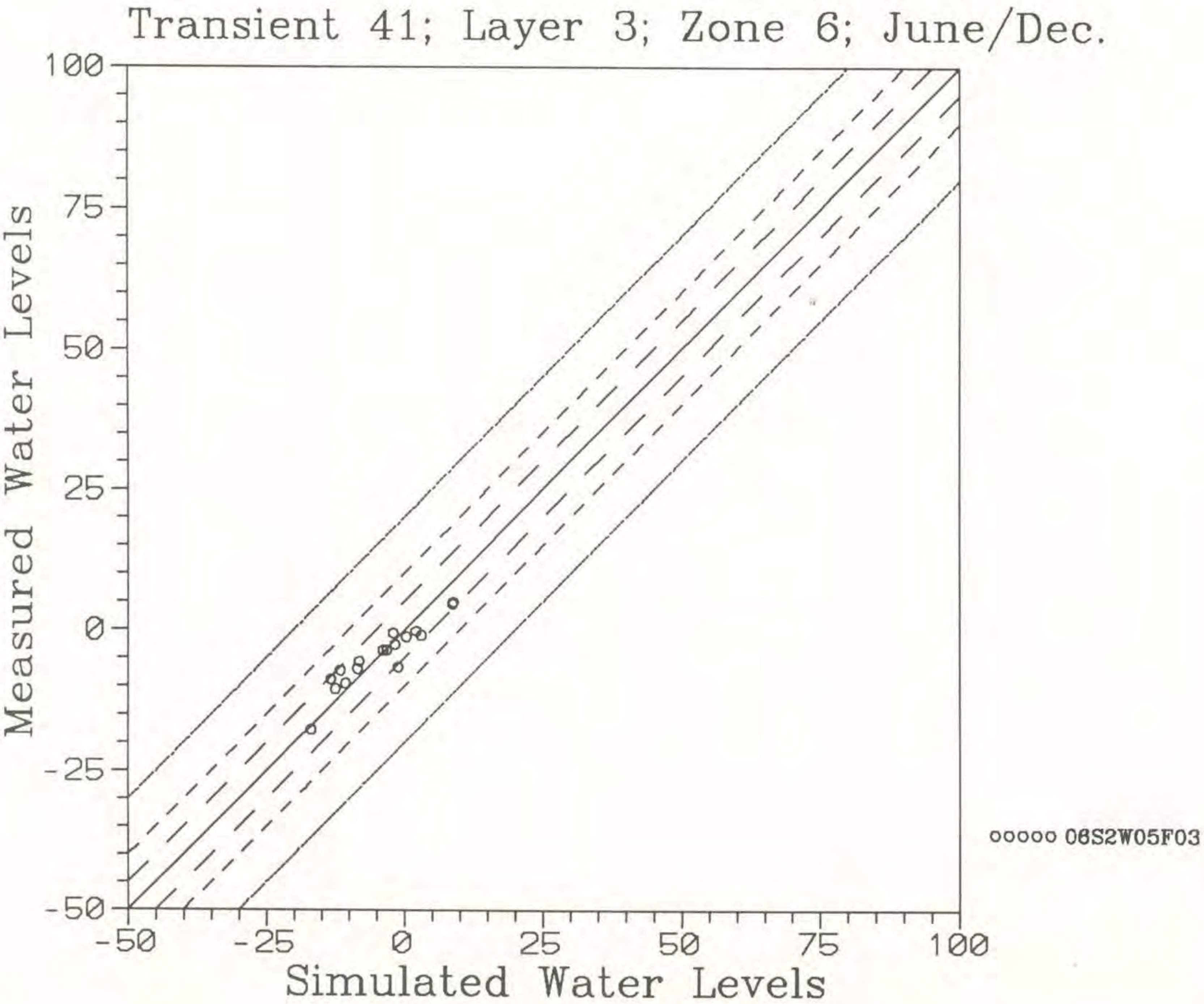
Transient 41; Layer 3; Zone 4; June/Dec.



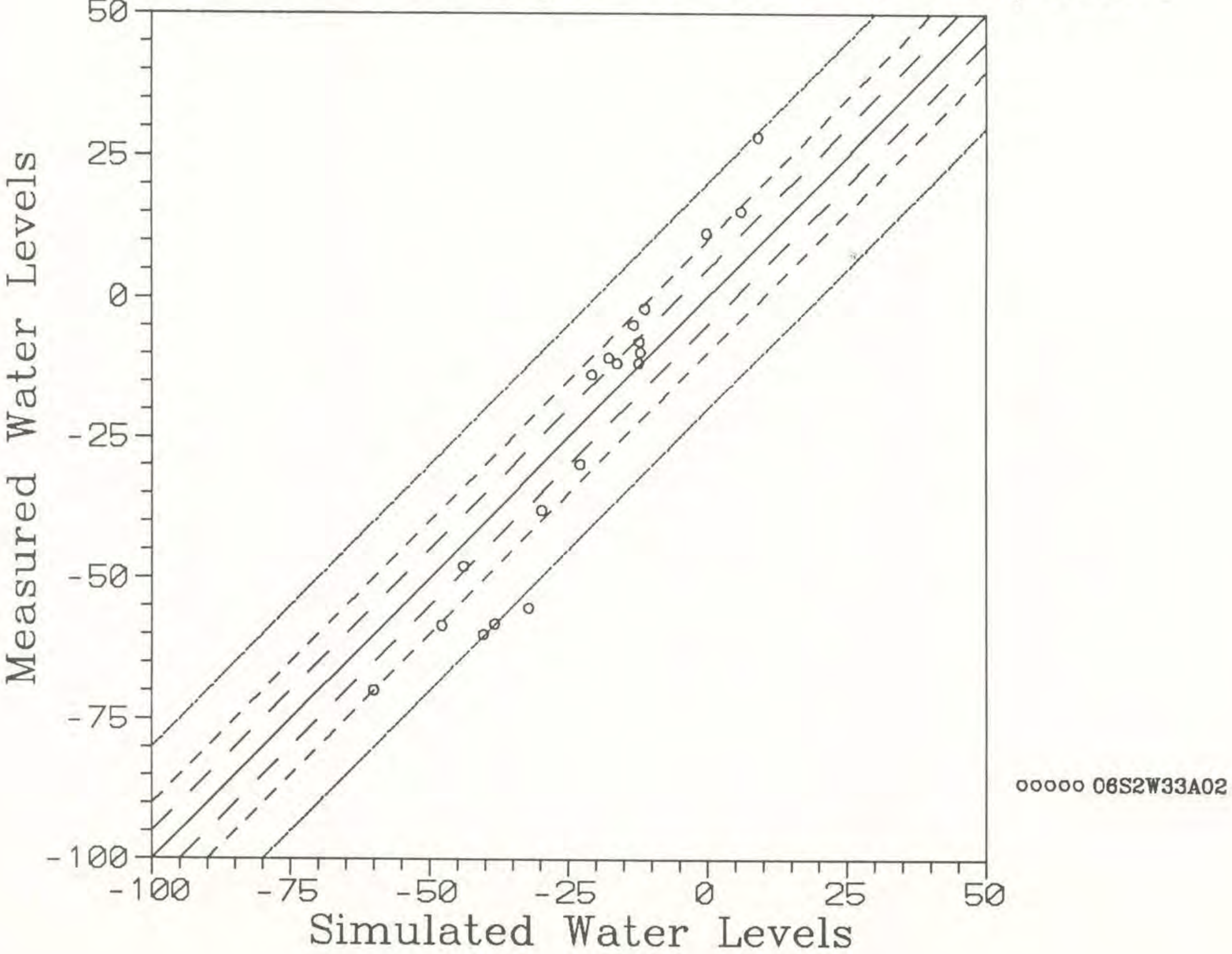

Transient 41; Layer 3; Zone 4; June/Dec.
Measured Water Levels
200
175
150
125
100
75
50
Simulated Water Levels
50
75
100
125
150
175
200
ooooo 08S1E11Q01

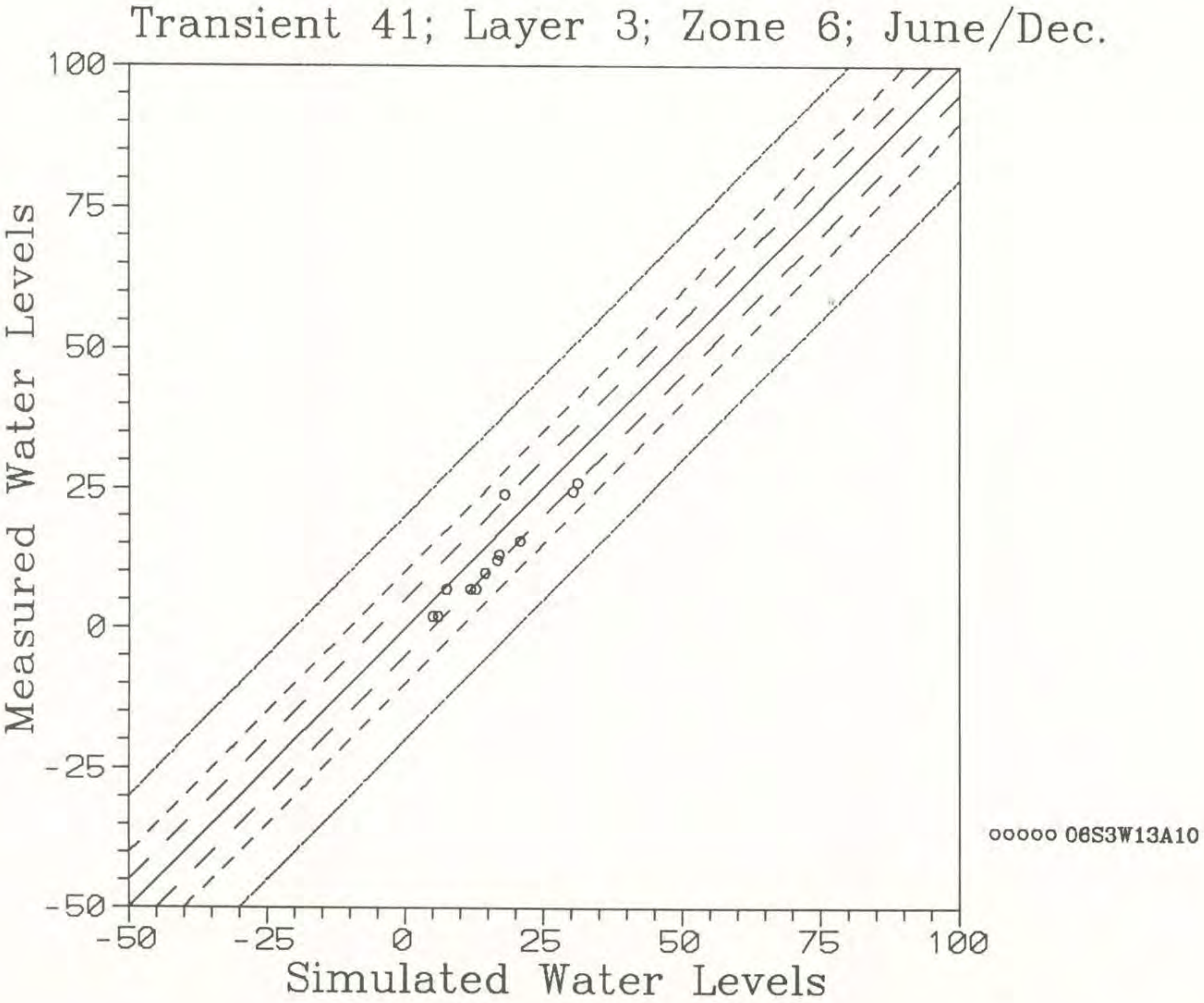

Transient 41; Layer 3; Zone 4; June/Dec.
Measured Water Levels
200
175
150
125
100
75
50
Simulated Water Levels
50
75
100
125
150
175
200
ooooo 08S1E15C02

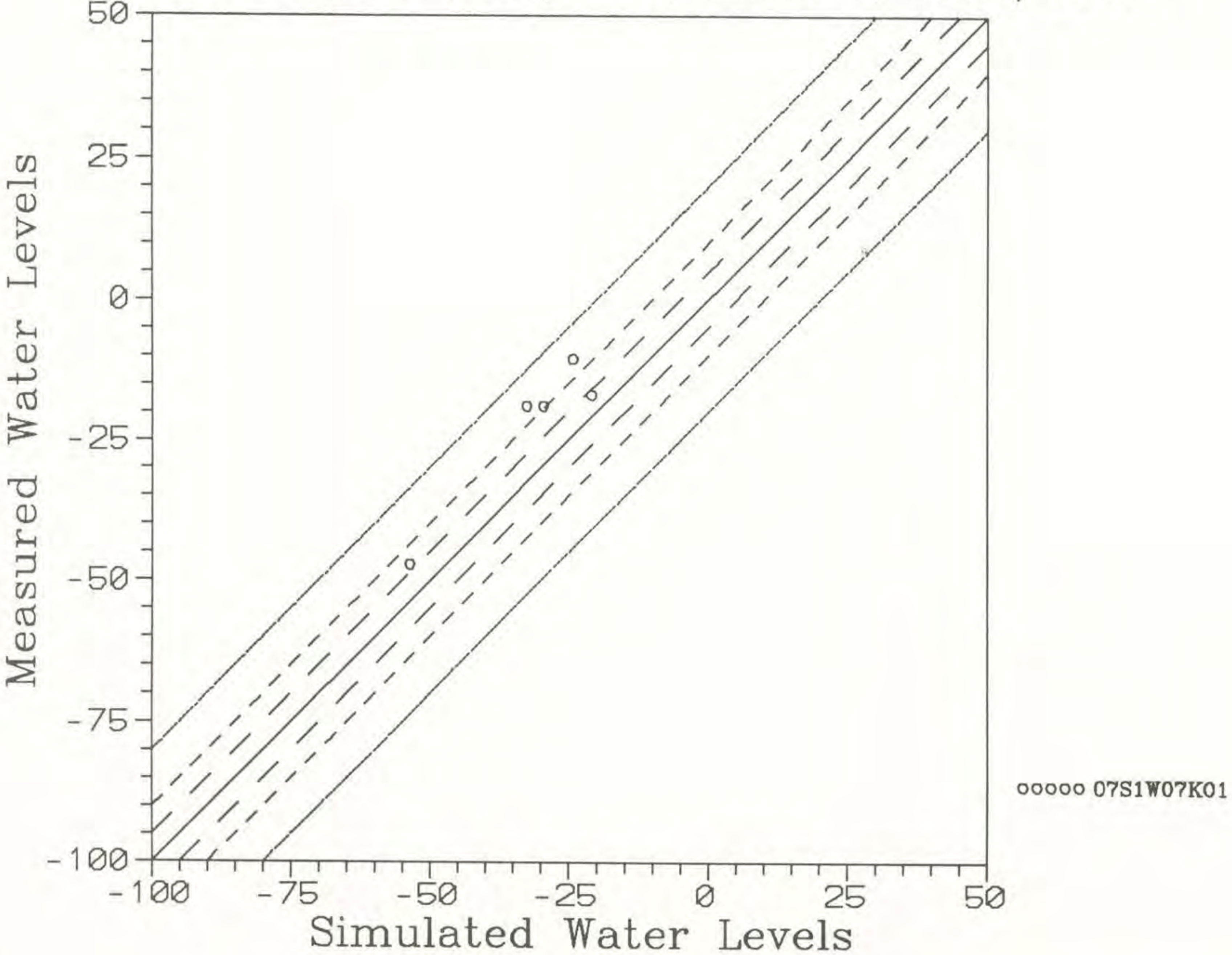

Transient 41; Layer 3; Zone 5; June/Dec.
Measured Water Levels
100
75
50
25
0
-25
-50
Simulated Water Levels
-50
-25
0
25
50
75
100
ooooo 05S2W32F10


Transient 41; Layer 3; Zone 6; June/Dec.
Measured Water Levels
100
75
50
25
0
-25
-50
-50
-25
0
25
50
75
100
Simulated Water Levels
ooooo 06S2W05F03

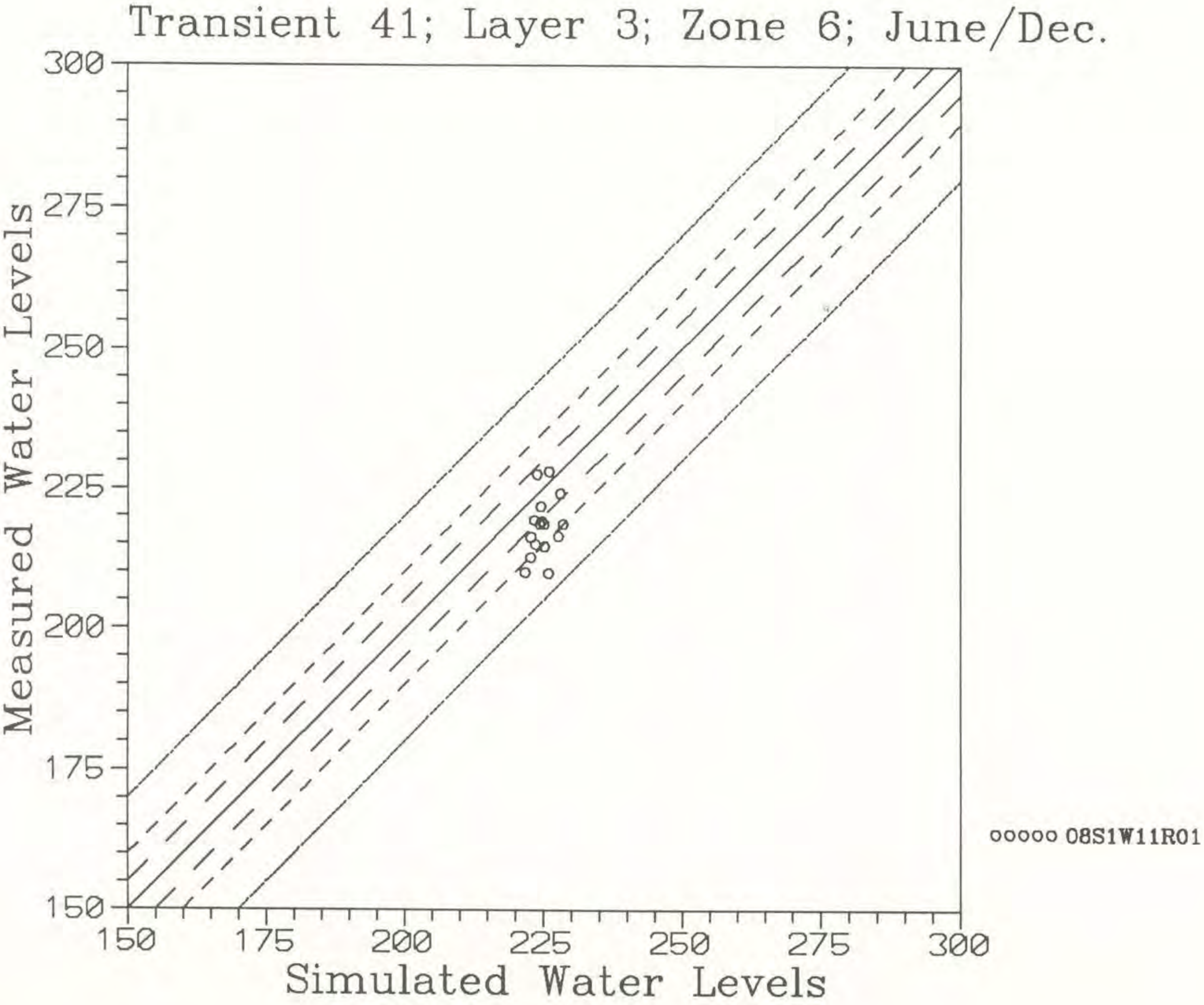
Transient 41; Layer 3; Zone 6; June/Dec.

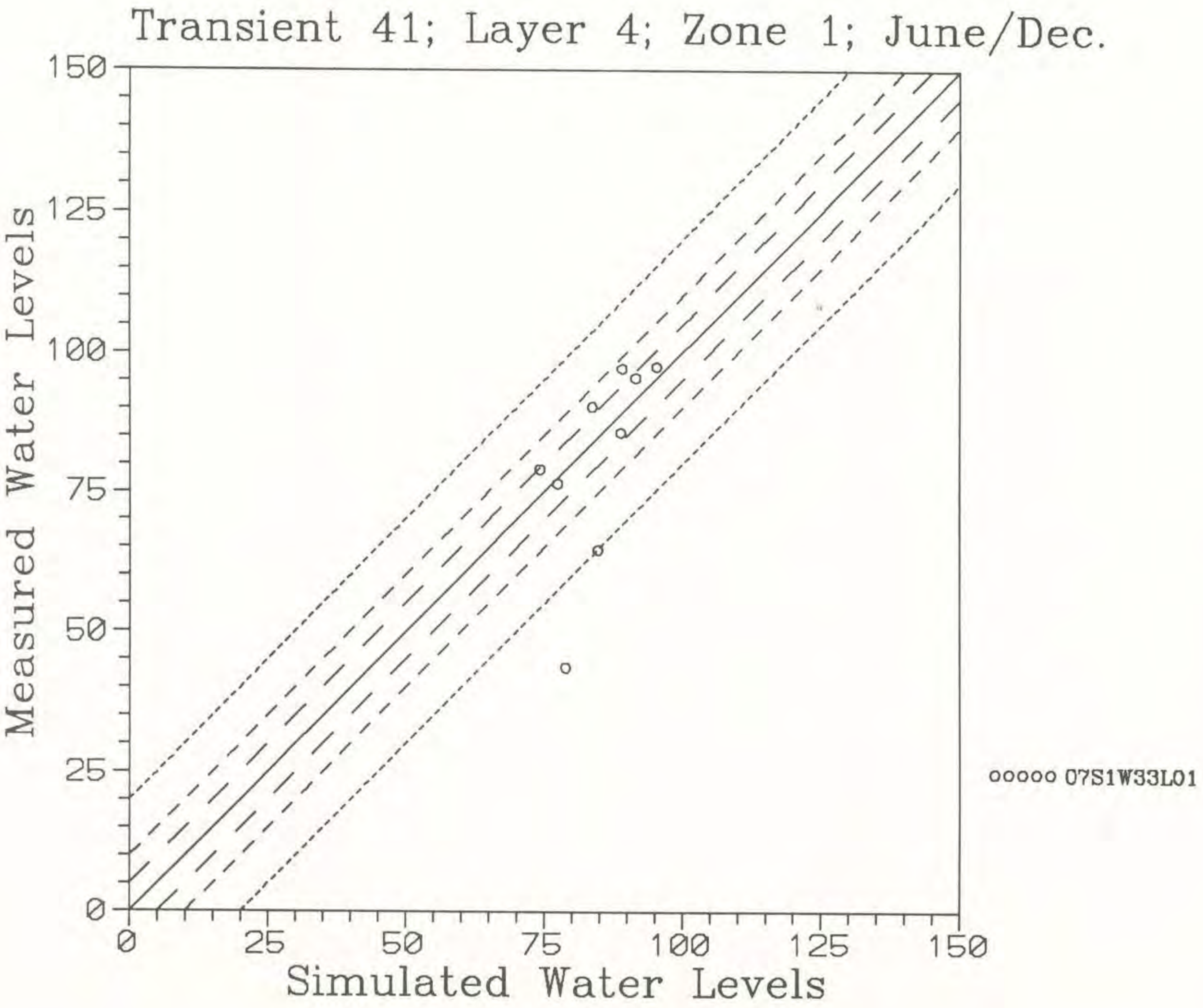


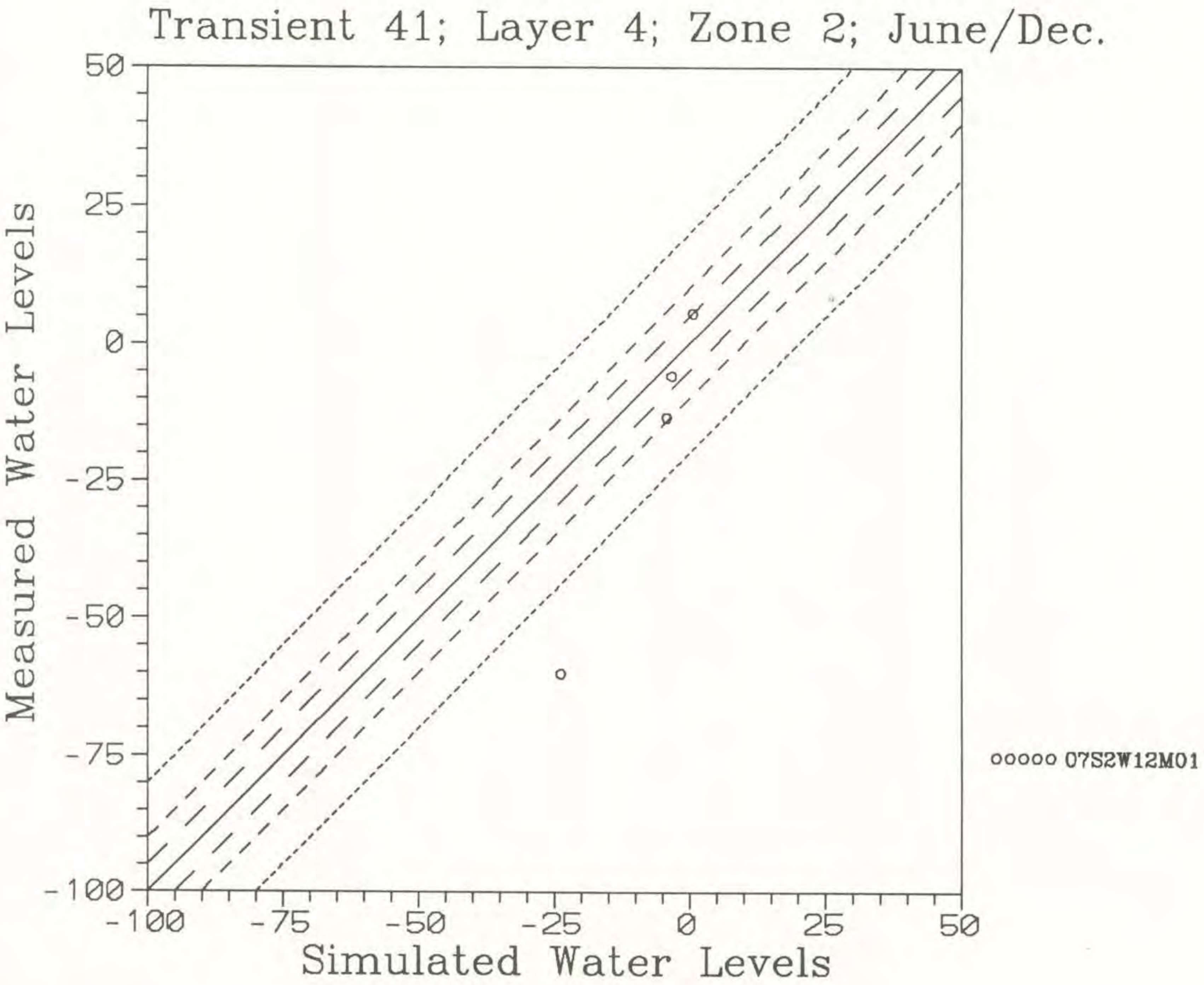

Transient 41; Layer 3; Zone 6; June/Dec.
Measured Water Levels
100
75
50
25
0
-25
-50
Simulated Water Levels
-50
-25
0
25
50
75
100
ooooo 06S3W13A10

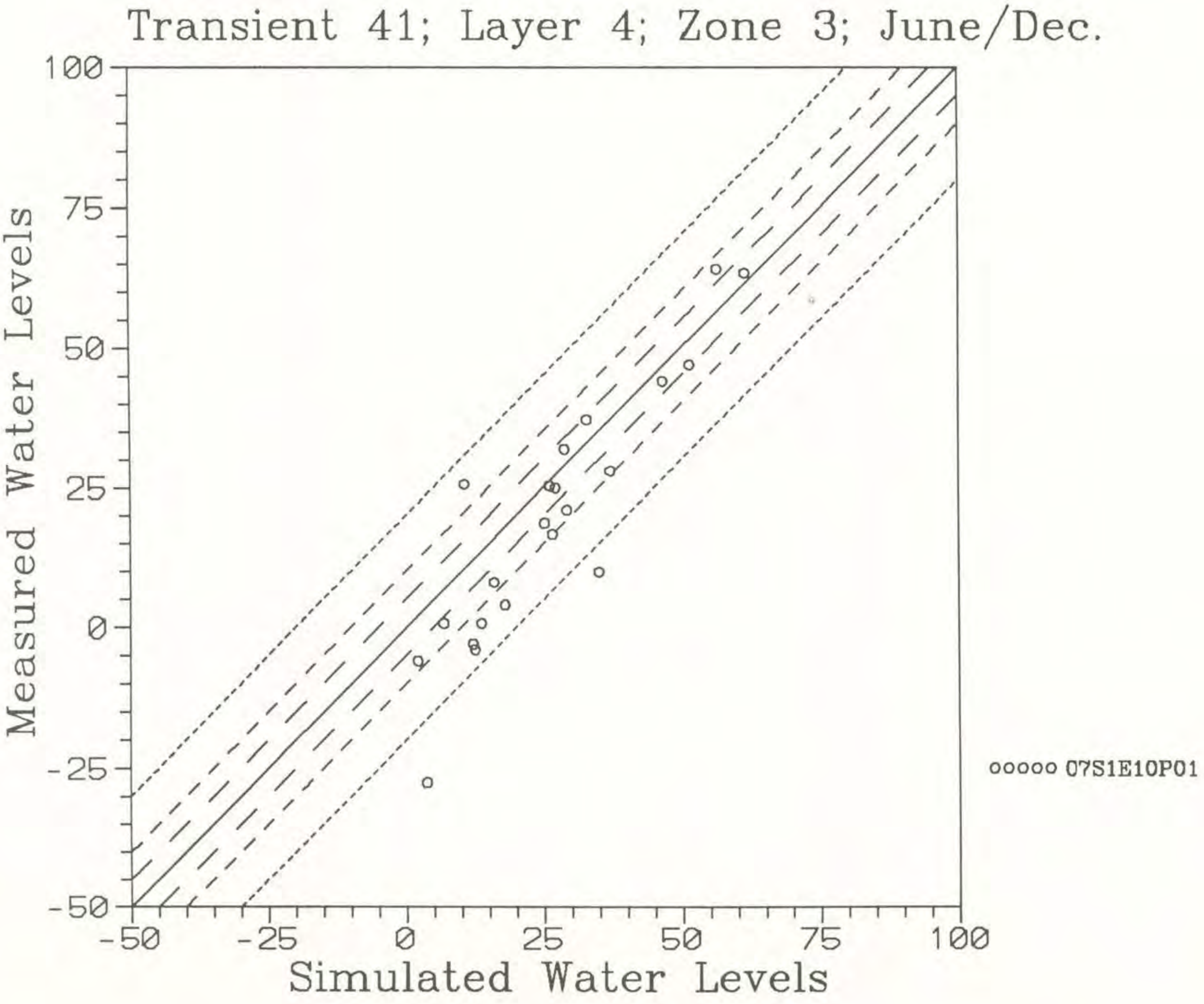


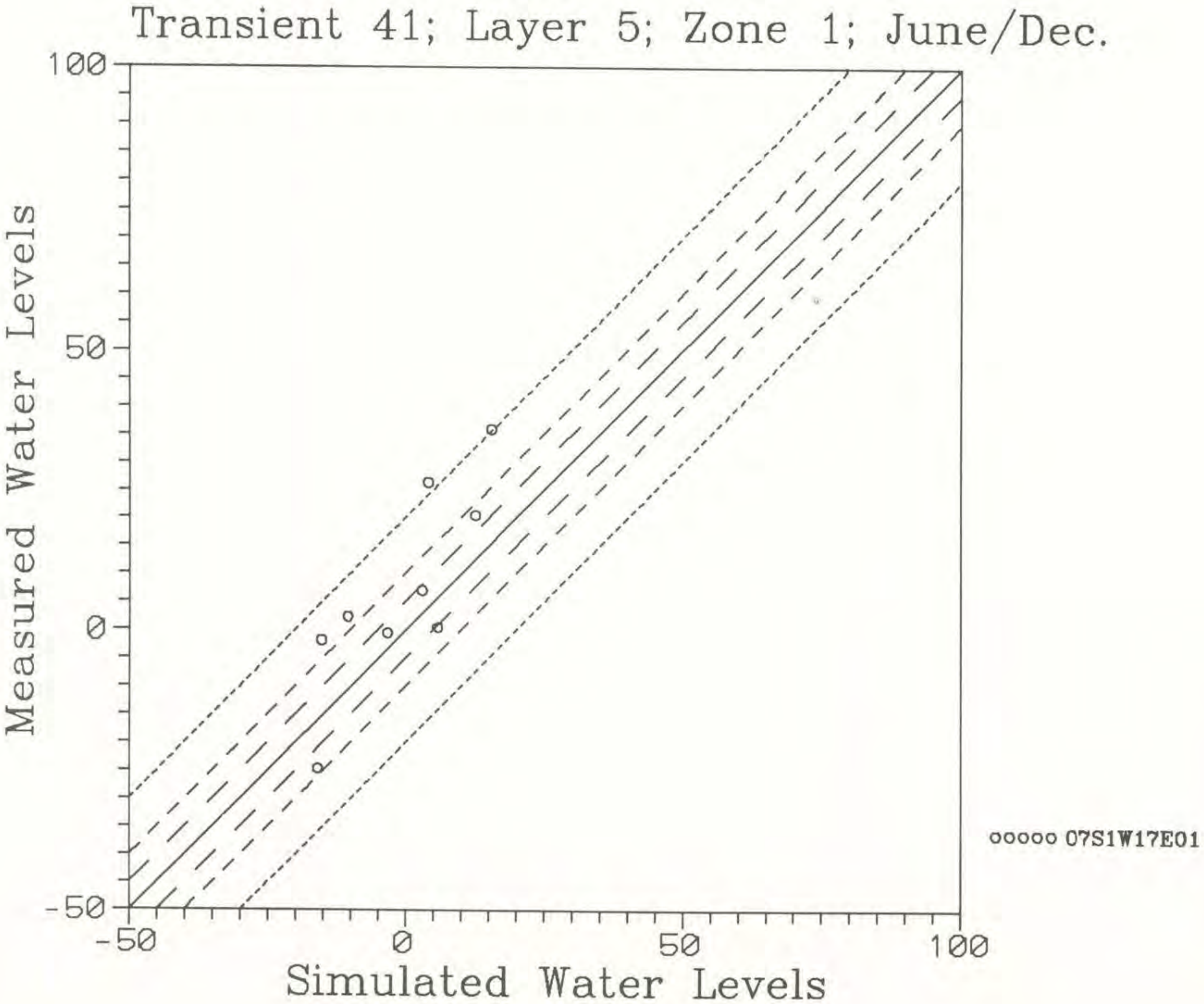
Transient 41; Layer 3; Zone 6; June/Dec.

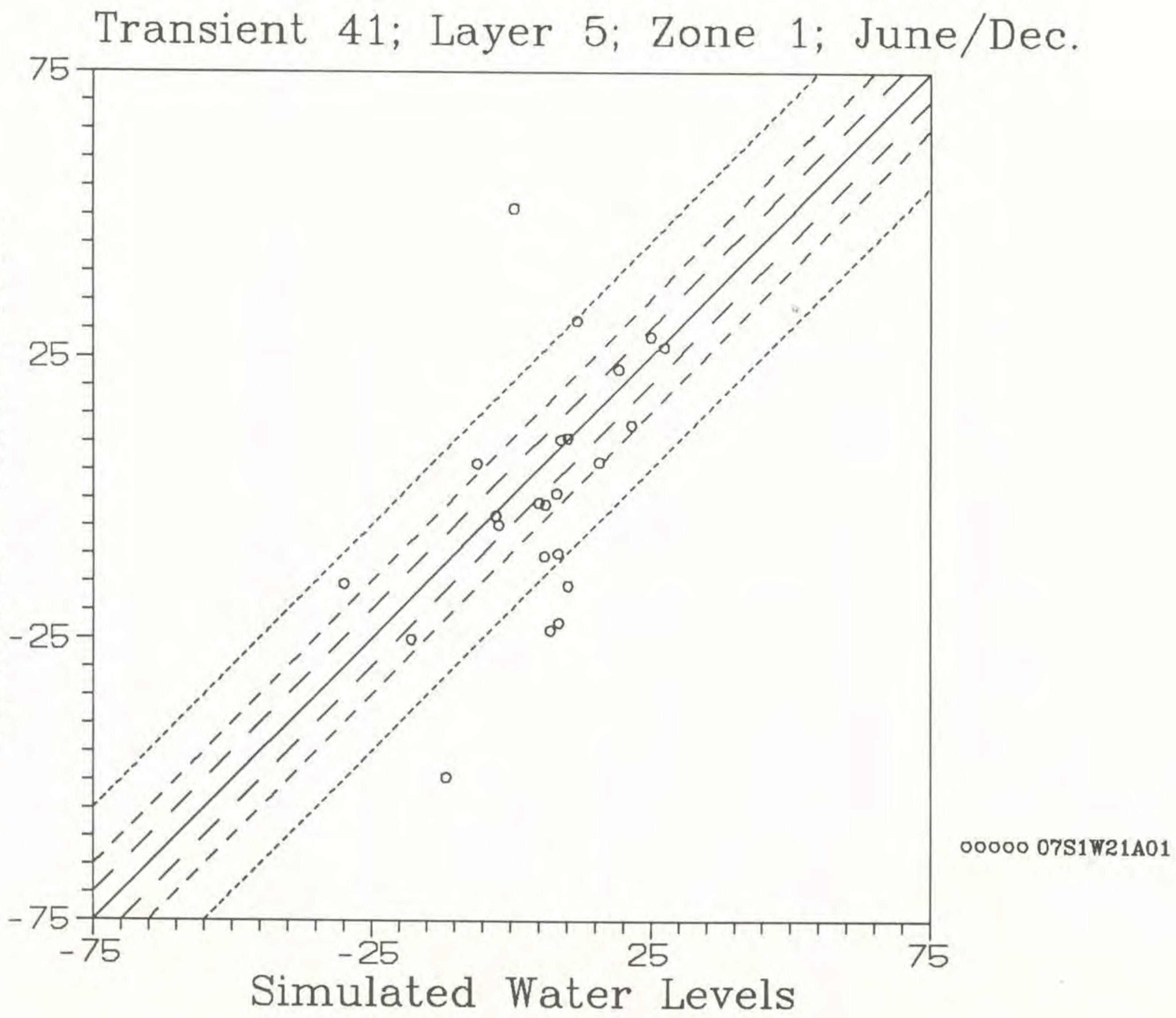

Transient 41; Layer 3; Zone 6; June/Dec.
Measured Water Levels
300
275
250
225
200
175
150
150
175
200
225
250
275
300
Simulated Water Levels
ooooo 08S1W11R01

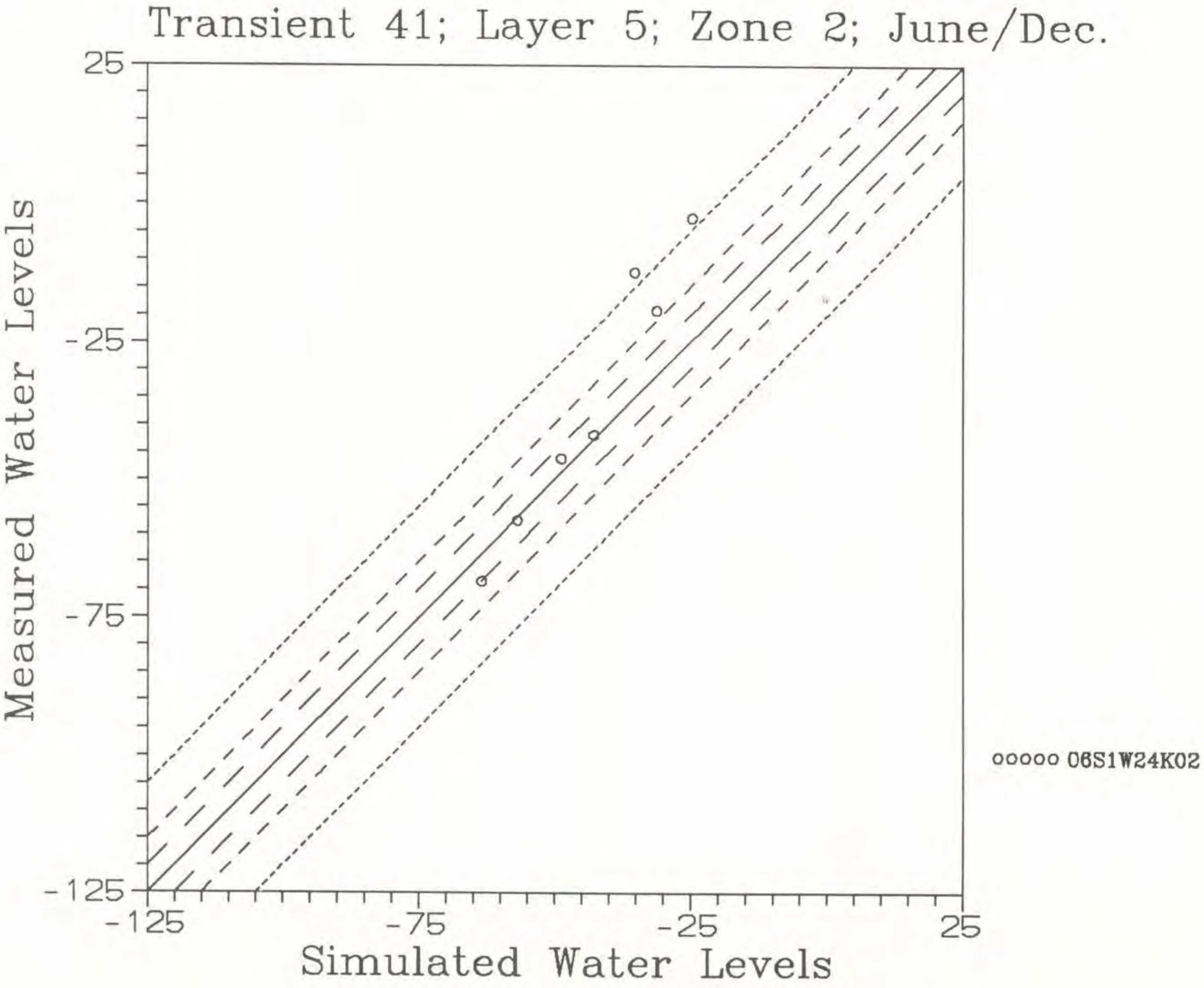

Transient 41; Layer 4; Zone 1; June/Dec.
Measured Water Levels
Simulated Water Levels
0
25
50
75
100
125
150
0
25
50
75
100
125
150
ooooo 07S1W33L01

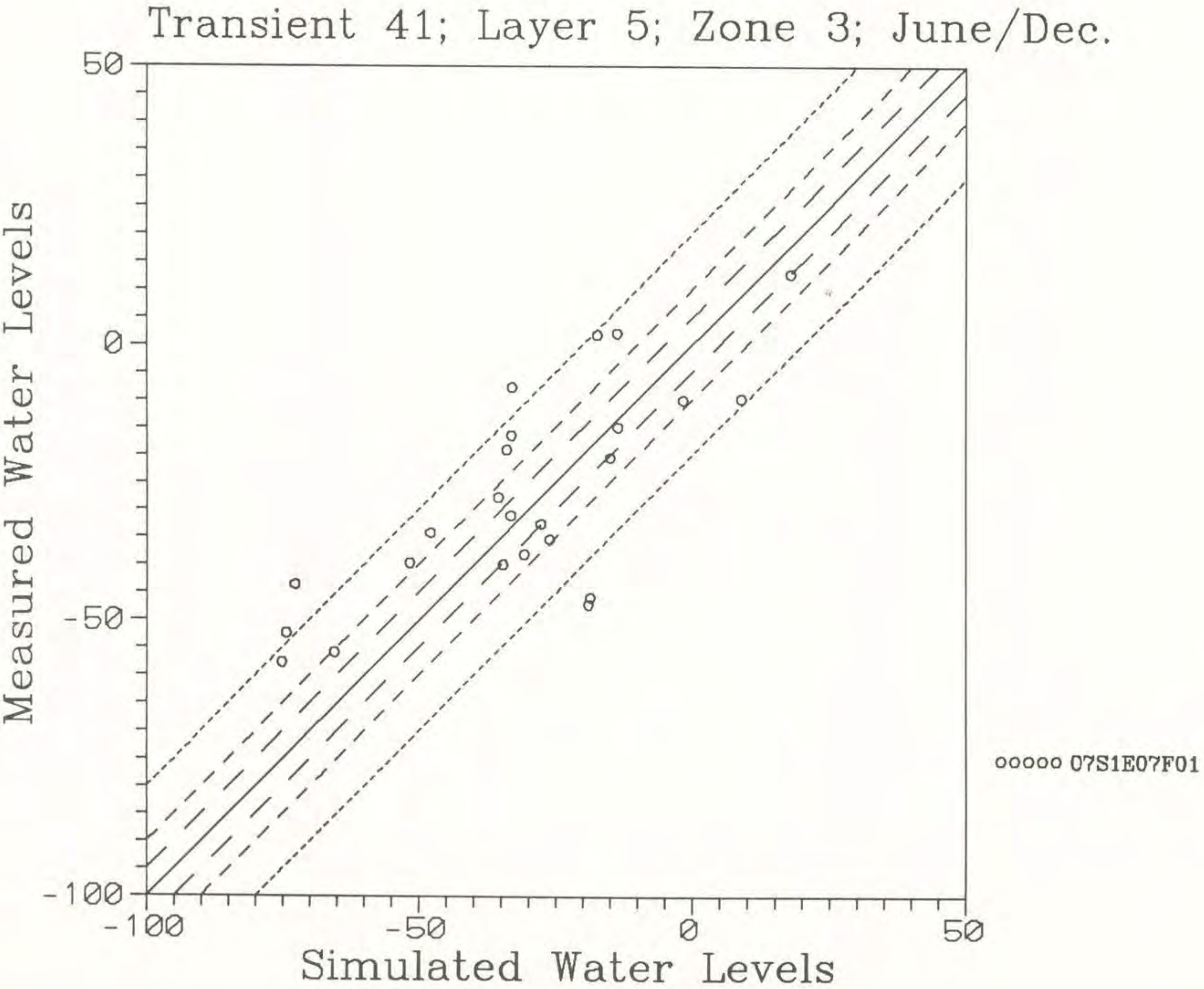

Transient 41; Layer 4; Zone 2; June/Dec.
Measured Water Levels
50
25
0
-25
-50
-75
-100
-100
-75
-50
-25
0
25
50
Simulated Water Levels
ooooo 07S2W12M01


Transient 41; Layer 4; Zone 3; June/Dec.
Measured Water Levels
100
75
50
25
0
-25
-50
-50
-25
0
25
50
75
100
Simulated Water Levels
ooooo 07S1E10P01

Transient 41; Layer 5; Zone 1; June/Dec.
Measured Water Levels
Simulated Water Levels
100
50
0
-50
-50
0
50
100
ooooo 07S1W17E01


Transient 41; Layer 5; Zone 1; June/Dec.
75
25
-25
-75
-75
-25
25
75
Measured Water Levels
Simulated Water Levels
ooooo 07S1W21A01


Transient 41; Layer 5; Zone 2; June/Dec.
Measured Water Levels
25
-25
-75
-125
-125
-75
-25
25
Simulated Water Levels
ooooo 06S1W24K02


Transient 41; Layer 5; Zone 3; June/Dec.
Measured Water Levels
Simulated Water Levels
50
0
-50
-100
-100
-50
0
50
ooooo 07S1E07F01

Appendix E

Limitations of Hydrograph Calibration

This appendix describes some limitations of hydrograph calibration resulting from the Santa Clara Valley Basin numerical model's discretization of space and time.

Types of Graphical Errors in Calibrating to Well Hydrographs

Figure E-1 presents schematic examples of five types of graphical error in calibrating to well hydrographs.

Factors Responsible for Well Hydrograph Calibration Error

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The ability of the Santa Clara Valley Basin numerical model to accurately match measured well hydrographs is limited by a number of factors. These include:

- Layer-by-layer water levels simulated by the model are only an approximation of the basin's true multiple piezometric surfaces.
- The model's zones of similar aquifer properties are only an approximation of the basin's true hydrogeologic heterogeneity.
- Simulated water level errors result from inexact model input (e.g., estimated facility recharge, initial conditions, etc.).
- Point or line recharge is distributed instantaneously within model cells.
- Hydrologic conditions may differ between an end-of-quarter simulated water level and the closest time of a measured water level.
- Water levels simulated for a model node (a cell of a particular layer) with pumping only represent water levels at an effective radius from the simulated pumping well.
- Simulated water levels represent quarter-averaged pumping; they may not match measured water levels if pumping varies significantly during a quarter.
- In confined zones, actual water levels may fluctuate significantly because of daily pumping cycles; although influencing water level measurements, these fluctuations are not simulated by the model.

This appendix presents analytical examples of the last three factors.

Simulated Water Levels in Nodes with Pumping

Table E-1 presents autumn 1977 average pumping rates for model cells with and near selected calibration wells. This table reflects a successful effort to select calibration wells away from large producing wells. For the 29 calibration wells listed, only four wells had pumping in the same node during autumn 1977; of these, the maximum pumping rate within the same node was only 63 gallons per minute (gpm). Note, however, that Calibration Well 7S1E07R99, representative of Model Layer 3, had significant pumping from nodes in layers immediately beneath it (over 12,000 gpm in autumn 1977).

Although pumping from the same nodes as calibration wells does not appear to have been a potential problem during calibration, future model users may wish to accurately simulate water levels in nodes with pumping wells. To do so, the following correction presented by Bredehoeft (1990) should be applied.

The water level simulated in any node can be viewed as an average water level within that node, including nodes that contain pumping. The water level calculated for a node with pumping is equivalent to the water level caused by a single production well observed at an effective radius, r_e, estimated by the formula:

$$r_e = 0.28(\mathrm{DELR}^2 + \mathrm{DELC}^2)^{1/2}$$

where DELR and DELC are the row and column node dimensions in feet, respectively. For example, the effective radii for various node dimensions are:

DELR	DELC (feet)	r_e
1,000	1,000	396
1,000	2,000	626
2,000	2,000	792
1,000	3,000	885
2,000	2,000	1,010

Figures E-2 and E-3 are Theis equation distance-drawdown curves illustrating water-level corrections for a 1,000-foot-square node, at the end of one quarter, and with 1,000 gpm pumping from a well at the center of the cell. The assumed transmissivities are representative of nodes with calibration wells in the confined and recharge zones (Table E-1).

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Table E-1
Pumping in Model Cells Near Calibration Wells
Autumn 1977

			CELL TRANSMISSIVITY (ft^2/day)				CELL PUMPAGE (gpm)				PUMPAGE OF NEAREST 8 CELLS (gpm)				PUMPAGE OF NEAREST 24 CELLS (gpm)			
							LAYER				LAYER				LAYER			
STATE WELL NUMBER	CALIBRATION LAYER	MODEL CELL	3	4	5	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5	ALL
Confined Zone																		
5S2W32F10	3	1610	2610	730	1575	4915	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0
6S1E29G06	3	1253	4860	1550	2570	8980	**0**	38	0	38	**39**	136	11	186	**547**	1292	269	2108
6S1E32M05	1	1653	15300	8525	14245	38070	0	0	0	0	0	0	0	0	271	1154	258	1683
6S1W21J01	3	1833	6000	4060	3400	13460	**31**	71	0	102	**31**	71	0	102	**31**	71	0	102
6S1W22H01	2	1435	5400	4180	3740	13320	7	11	8	26	121	422	69	612	375	625	106	1106
6S1W24K02	5	1242	15100	3540	4180	22820	74	42	**30**	146	255	208	**109**	572	805	541	**287**	1633
6S1W35K01	2	2141	4890	9625	10725	25240	0	0	0	0	262	117	85	464	270	142	1038	1450
6S2W03N01	3	1915	5160	2700	5100	12960	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0
6S2W05F03	3	2011	870	705	1535	3110	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0
6S2W13F01	3	2022	5250	3020	4380	12650	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0
6S2W22H04	1	2820	860	3160	4780	8800	0	0	0	0	226	245	0	471	306	433	0	739
6S2W33A02	3	3820	850	2090	2410	5350	**0**	0	0	0	**42**	250	21	313	**160**	669	38	867
6S3W13A10	3	3210	880	1740	3310	5930	**0**	0	0	0	**0**	0	0	0	**17**	33	12	62
7S1E06L01	3	2252	14700	8635	14135	37470	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0
7S1E07F01	5	2654	15100	8635	14740	38475	0	0	**0**	0	303	355	**0**	658	**303**	355	0	658
7S1E07R99	3	2757	15400	8415	14795	38610	**17**	1757	10568	12342	**17**	1757	10568	12342	**320**	2112	10568	13000
7S1E10P01	4	2069	17500	1570	2300	21370	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0
7S1W02G01	3	2543	5070	9570	11660	26300	**0**	0	130	130	**80**	98	1192	1370	**80**	107	1616	1803
7S1W07K01	3	4133	990	1990	2290	5270	0	0	0	0	**131**	119	0	250	**185**	140	0	325
7S1W17E01	5	4435	2015	2000	2430	6445	0	0	**0**	0	23	54	**55**	132	135	110	**82**	327
7S1W21A01	5	4242	1030	1930	2570	5530	0	0	**0**	0	0	0	**0**	0	739	1857	**1614**	4210
Recharge Zone																		
7S1W33L01	4	5046	1700	1910	3190	6800	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0
7S1W12M01	4	4528	1920	4040	4780	10740	0	**0**	0	0	63	**256**	89	408	221	**933**	132	1286
8S1E02R01	3	3980	96666	790	2130	99586	**63**	0	0	63	**788**	0	0	788	**800**	0	0	800
8S1E05N01	3	4771	47000	970	2480	50450	**0**	0	0	0	**0**	0	0	0	**887**	0	0	887
8S1E10J01	3	4478	45700	980	2270	48950	**0**	0	0	0	**456**	0	0	456	**615**	0	0	615
8S1E11Q01	3	4481	46800	820	2270	49890	**0**	0	0	0	**0**	0	0	0	**998**	0	0	998
8S1E15C02	3	4778	15600	1090	2360	19050	**0**	0	0	0	**102**	0	0	102	**678**	0	0	678
8S1W11R01	3	5264	1340	1050	2680	5070	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0

For the confined-zone example (Figure E-2), the assumed aquifer properties are a transmissivity (T) of 30,000 gallons per day per foot (gpd/ft) and a storativity (S) of 0.0001. Given that r_e is about 400 feet, the model underestimates drawdown by about 10 feet compared to an observation well 100 feet from the pumping well (r=100) and overestimates drawdown by about 7 feet compared to an observation well at r=1,000 feet.

For the recharge zone (Figure E-3), the assumed aquifer properties are a T of 100,000 gpd/ft and a specific yield (Sy) of 0.07. The model underestimates drawdown by about 3 feet compared to an observation well at r=100 feet and overestimates drawdown by about 2 feet compared to an observation well at r=1,000 feet.

Effect of Quarter-Averaged Pumping

The model simulates water level changes through time in response to quarter-averaged pumping. The model may not reproduce actual, measured water levels if pumping varies significantly during a quarter.

Figures E-4 and E-5 are 2-year Theis equation time-drawdown curves for variable pumping conditions averaged over periods of 10, 30, and 90 days. Figures E-4a and E-4b represent confined conditions (T=30,000 gpd/ft, S=0.0001, observation well at r=2,000 feet) and Figures D-5a and D-5b represent unconfined conditions (T=100,000 gpd/ft, Sy=0.07, r=1,000 feet).

In Figures E-4a and E-5a, third quarter pumping: increases steadily from 900 gpm to 2,400 gpm when averaged over 10-day increments; increases from 1,000 gpm to 2,000 gpm when averaged over 30-day increments; and averages 1,500 gpm for the entire quarter. Such increases in pumping commonly occur during the summer quarter in the Santa Clara Valley Basin. In the confined case, the quarter-averaged pumping underestimates maximum drawdown by about 12 feet compared to 30-day averaged pumping, and nearly 20 feet compared to 10-day averaged pumping. During the water-level recovery of the following two quarters, the rise to peak-annual water levels is slightly out of phase (Figure D-1), causing the quarterly water levels to be about 10 feet below the monthly-averaged water levels. The unconfined case (Figure E-5a) illustrates similar, although less pronounced, water-level differences of 1 to 2 feet.

In Figures E-4b and E-5b, third quarter pumping averages 1,500 gpm but tends to decrease during the quarter when averaged over 10- and 30-day periods. Such decreases in pumping typically occur during the autumn quarter in Santa Clara Valley Basin. Compared to drawdowns estimated for 10- and 30-day periods, quarter-averaged drawdowns are out of phase during both peak drawdown and peak recovery. Compared to 30-day drawdowns in the confined case (Figure E-4b), the quarter-averaged drawdowns are about 12 feet smaller at the end of the third quarter, and

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10 feet greater at the end of the fourth quarter. The unconfined case (Figure E-5b) illustrates similar, although less pronounced, water-level differences of 1 foot.

Effect of Daily Pumping Cycles

The operation of wells may be cycled in response to the varying demand for water during each day. For this reason, water level measurements taken when area pumping wells are on or off will be lower or higher than average levels, respectively. Water levels simulated by the model for time steps of a day or greater will not reflect these daily fluctuations.

For confined and unconfined conditions, respectively, Figures E-6 and E-7 illustrate Theis-equation estimates of daily water level changes over a 90-day period in response a 1,000-gpm well operating 12 hours per day. In the confined case (Figure E-6; T=30,000 gpd/ft, S=0.0001, r=2,000 feet), daily water levels fluctuate about ±4 feet. This represents a potential simulation error in addition to the effects of quarterly-averaged pumping discussed previously. In the unconfined case (Figure E-7; T=100,000 gpd/ft, Sy=0.07, r=1,000 feet), daily water level fluctuations are insignificant.

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Summary

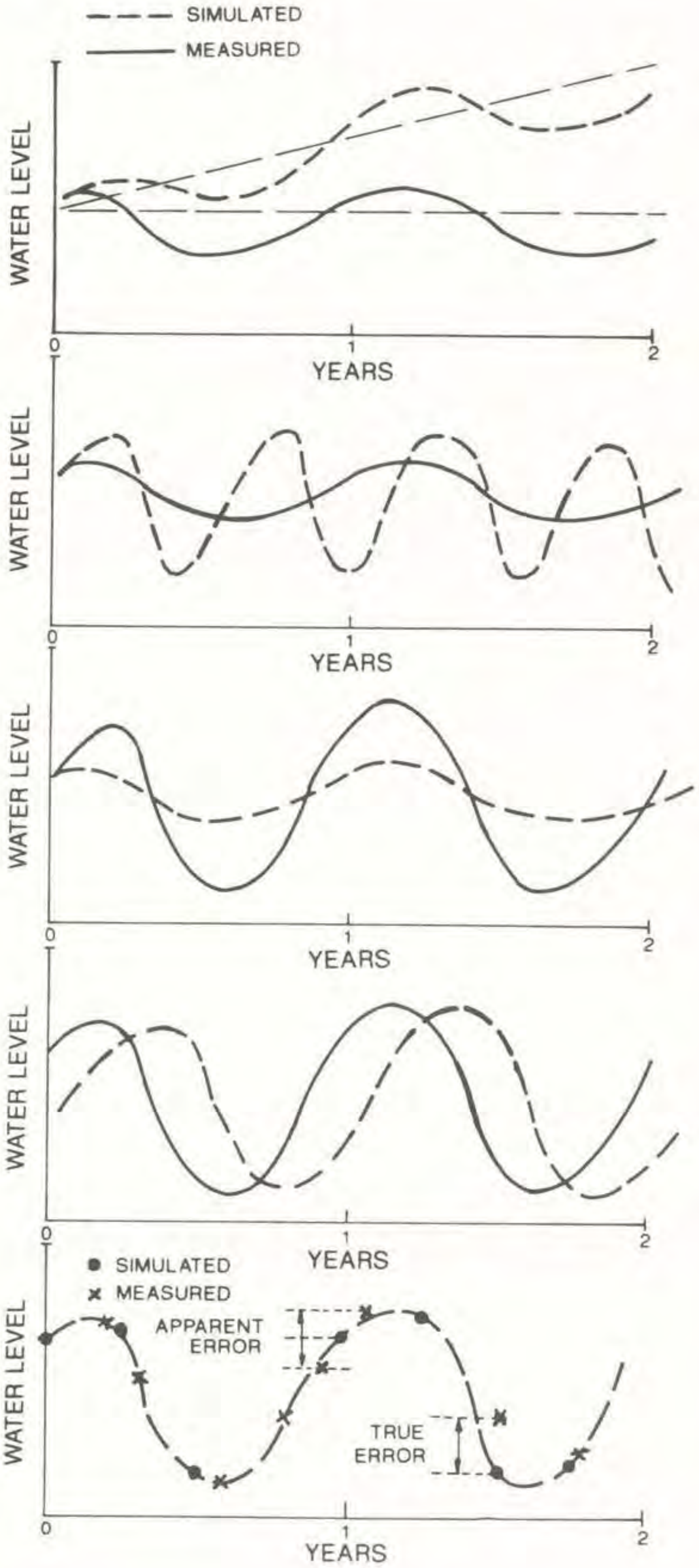
Given the confined and unconfined conditions assumed in the preceding examples, three potential calibration errors resulting from the Santa Clara Valley Basin numerical model's discretization of space and time may be summarized as follows:

Potential, Approximate Difference
Between Simulated and Measured Water Levels

	Confined Zone	Recharge Zone
Cells with Pumping	±5-10	±2
Quarter-Averaged Pumping	±10	±1-2
Daily Pumping Cycles	±4	≈0

References

Bredehoeft, J.D. 1990. Microcomputer Codes for Simulating Transient Ground-Water Flow: In Two and Three Space Dimensions. U.S. Geological Survey Open-File Report 90-559.



a. Long- Term Trend--
unparallel slopes

b. Seasonal Periodicity--
peaks and valleys do
not correspond

c. Amplitude of Seasonal
Minimum and Maximum
Peaks--peaks and valleys
dampened or heightened

d. Phase of Seasonal
Periodicity--out
of phase

e. Magnitude of Difference
Between Paired Points--
simulated quaterly water
level different than closest-
in-time measured level

FIGURE E-1

TYPES OF GRAPHICAL ERROR IN CALIBRATING TO WELL HYDROGRAPHS

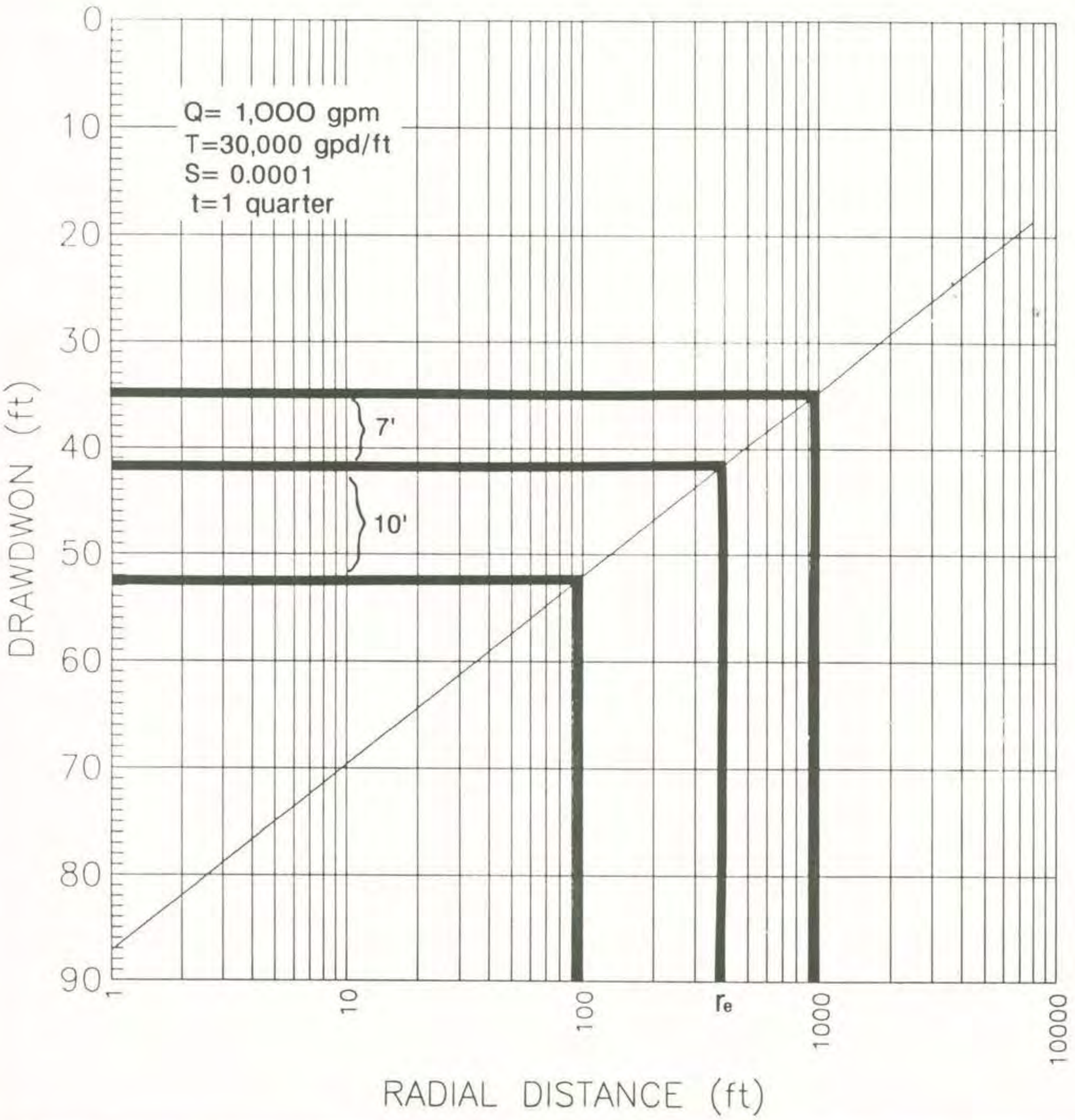


FIGURE E-2
THEIS ESTIMATES OF DISTANCE-DRAWDOWN FOR CONFINED CONDITIONS

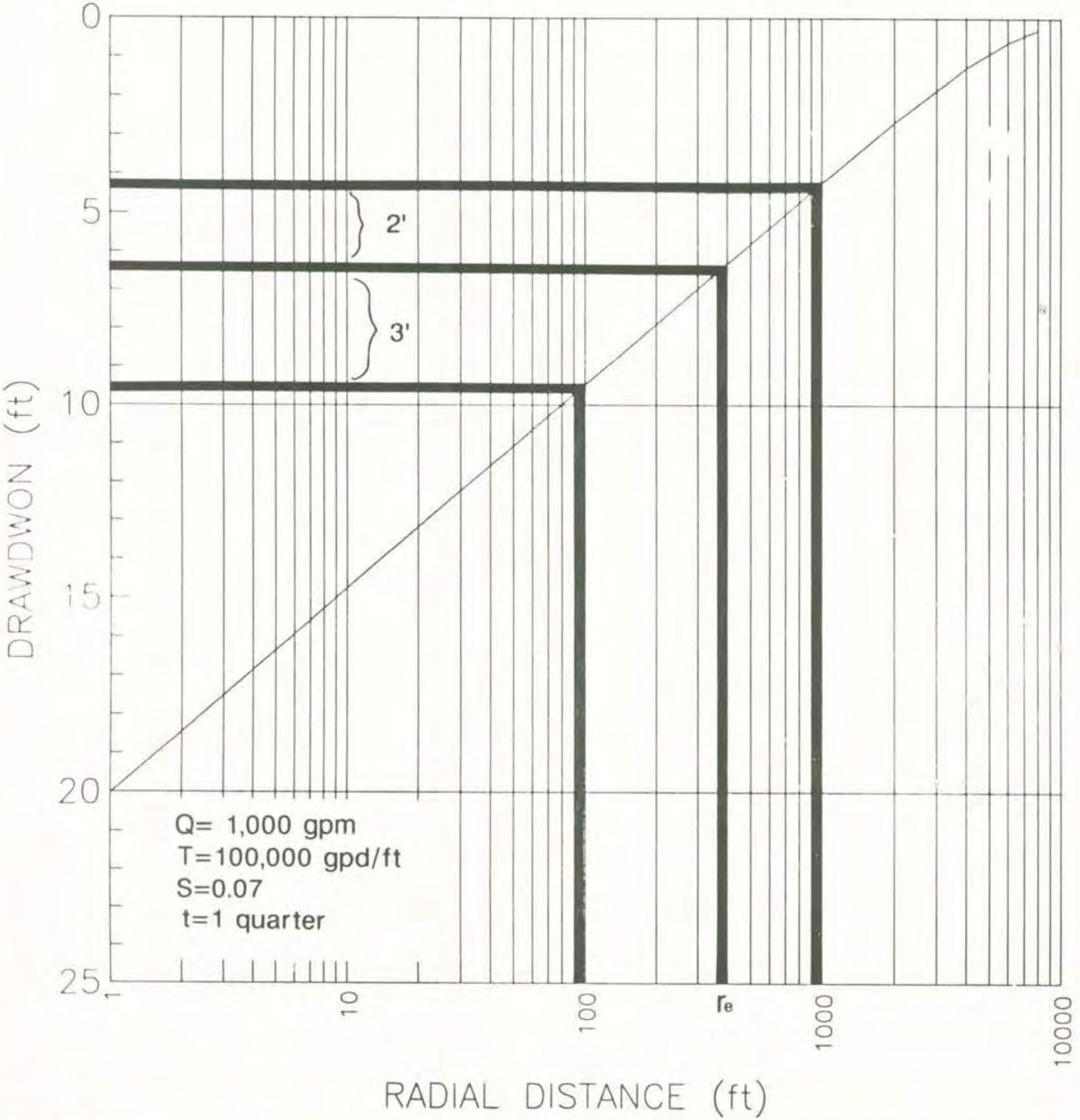


FIGURE E-3
THEIS ESTIMATES OF
DISTANCE-DRAWDOWN FOR
UNCONFINED CONDITIONS

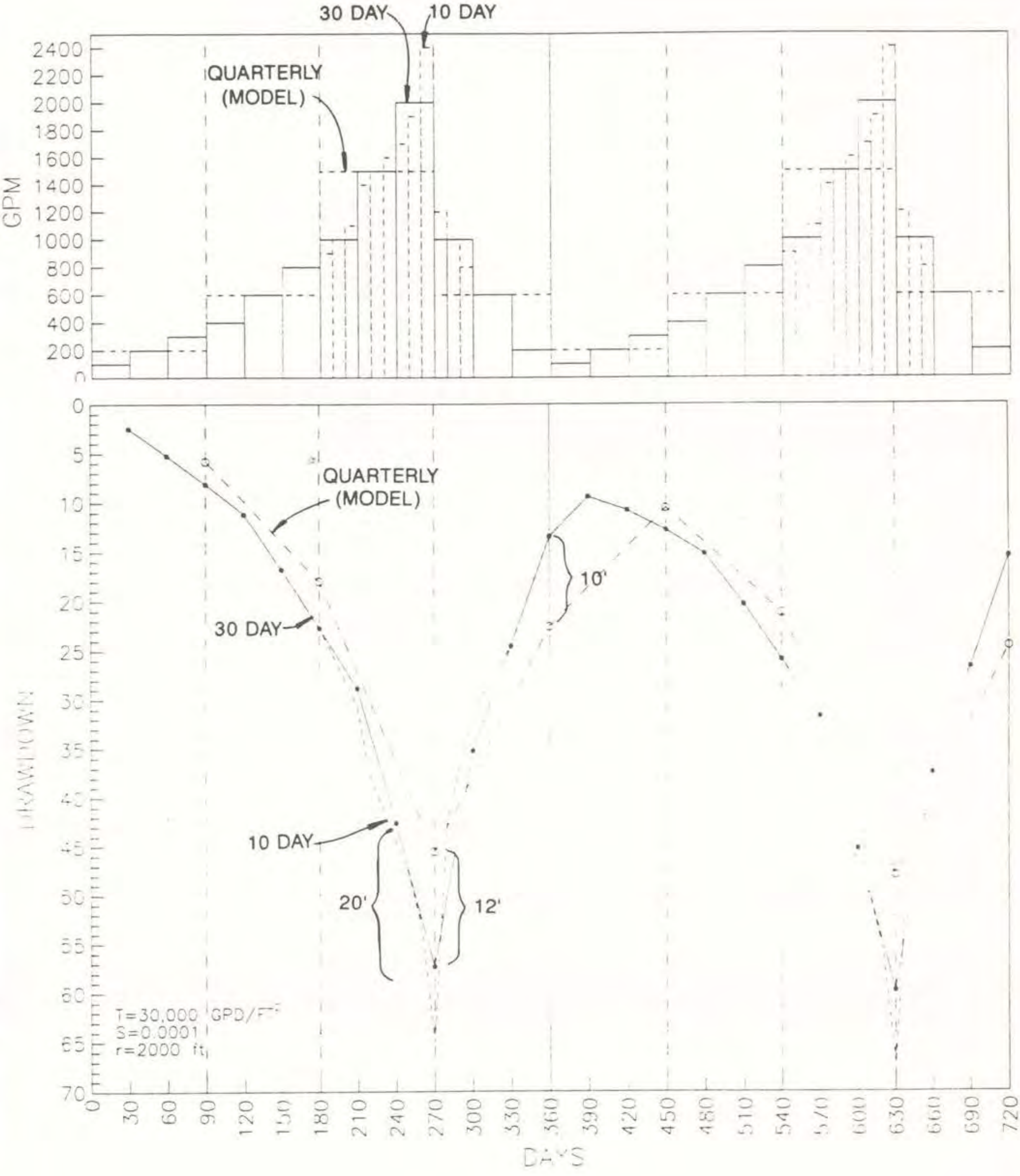


FIGURE E-4a
THEIS ESTIMATES OF TIME-DRAWDOWN FOR
CONFINED CONDITIONS AND VARIABLY AVERAGED PUMPING RATES

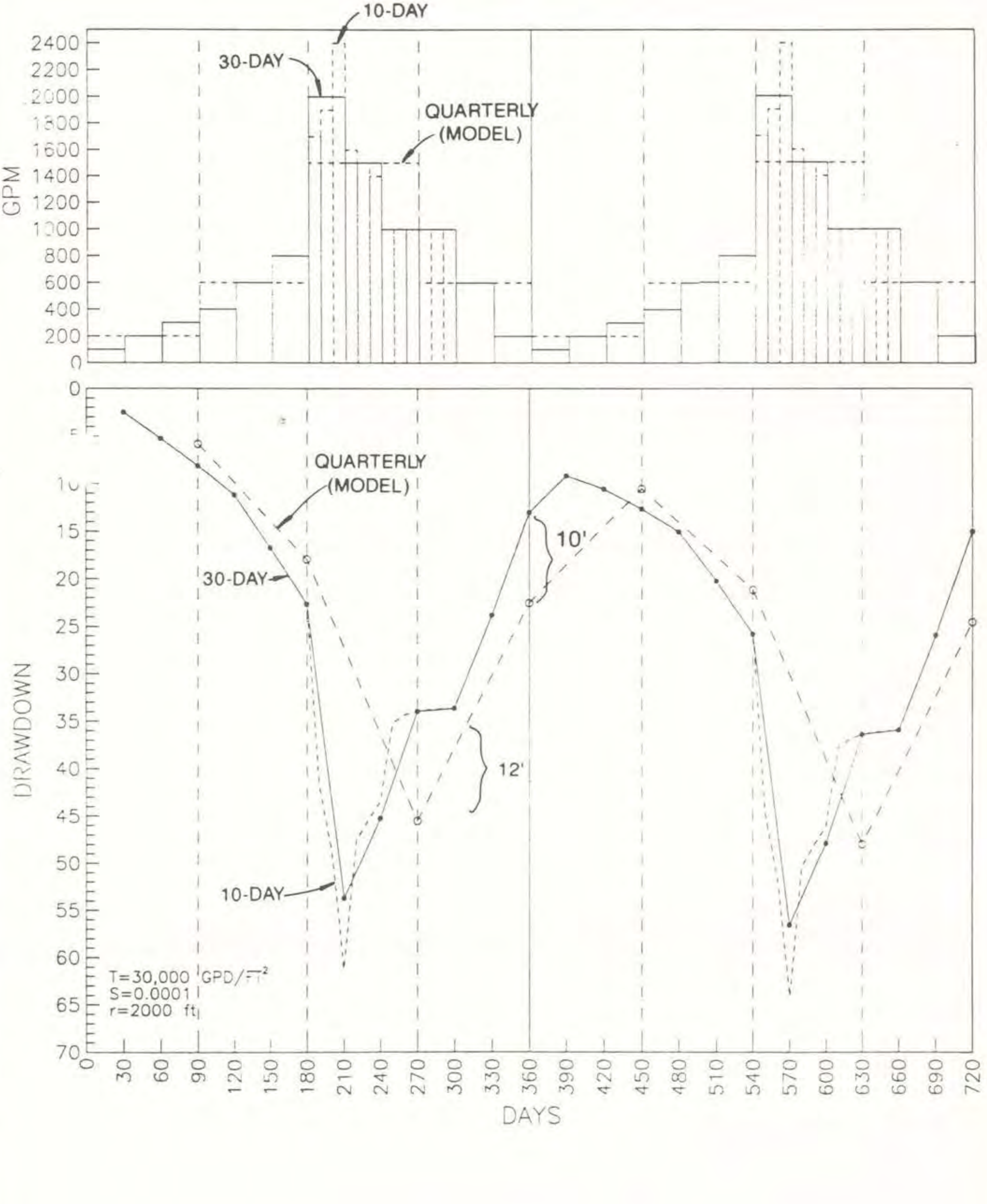


FIGURE E-4b

THEIS ESTIMATES OF TIME-DRAWDOWN FOR CONFINED CONDITIONS AND VARIABLY AVERAGED PUMPING RATES

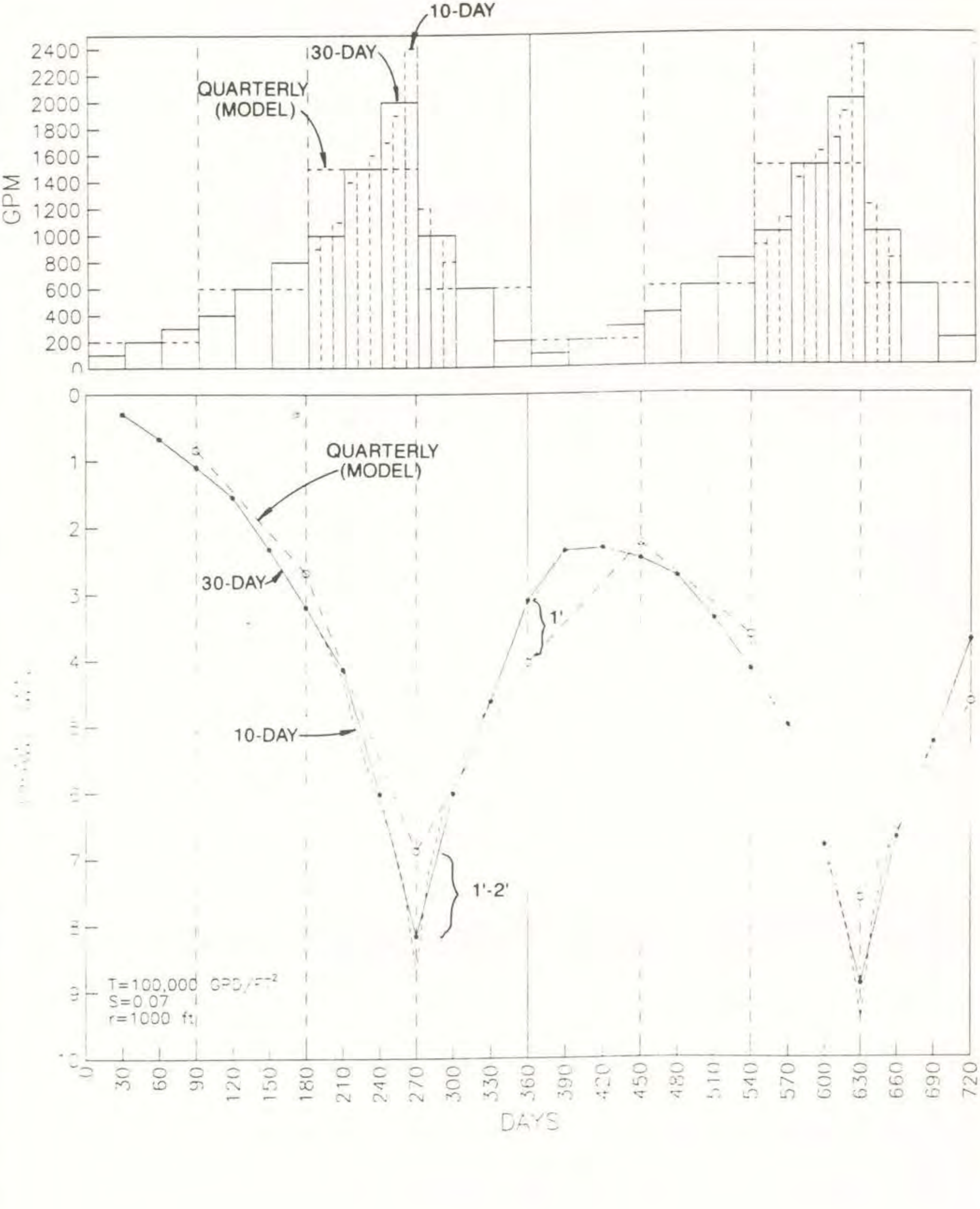


FIGURE E-5a
THEIS ESTIMATES OF TIME-DRAWDOWN FOR
UNCONFINED CONDITIONS AND VARIABLY AVERAGED PUMPING RATES

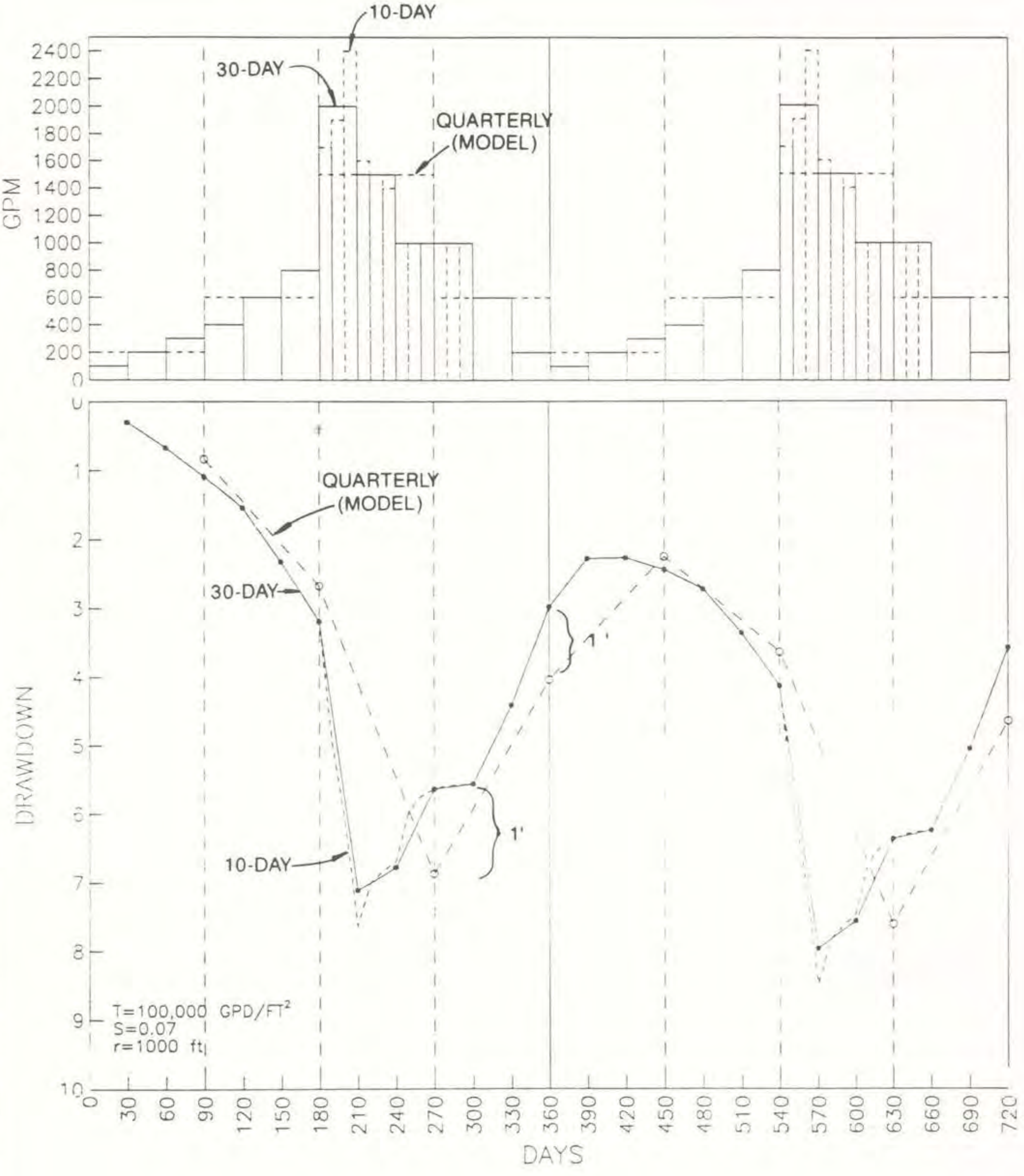


FIGURE E-5b

THEIS ESTIMATES OF TIMES-DRAWDOWN FOR UNCONFINED CONDITIONS AND VARIABLY AVERAGED PUMPING RATES

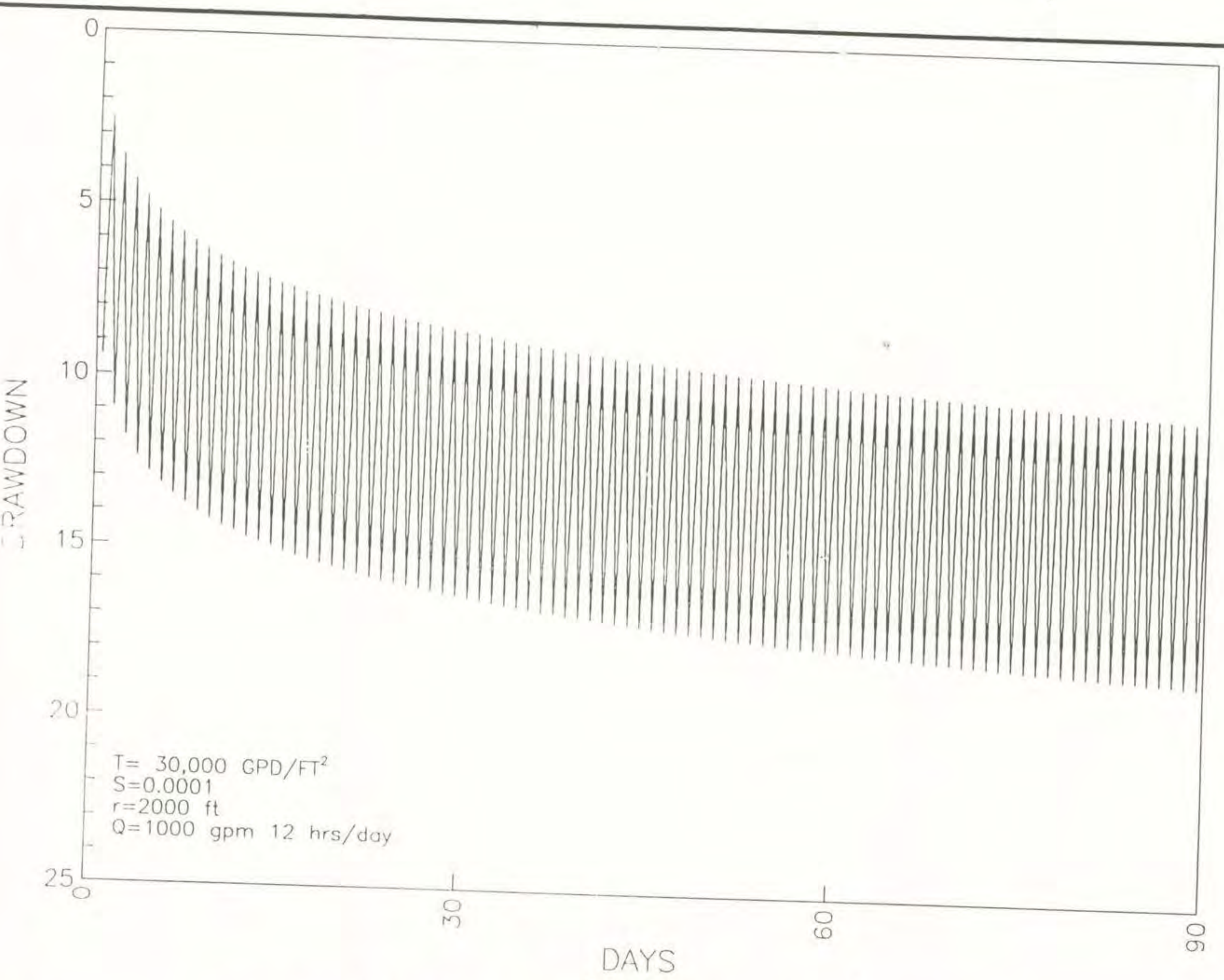


FIGURE E-6

THEIS ESTIMATE OF TIME-DRAWDOWN WITH 12-HOUR PUMPING CYCLES,CONFINED CONDITIONS

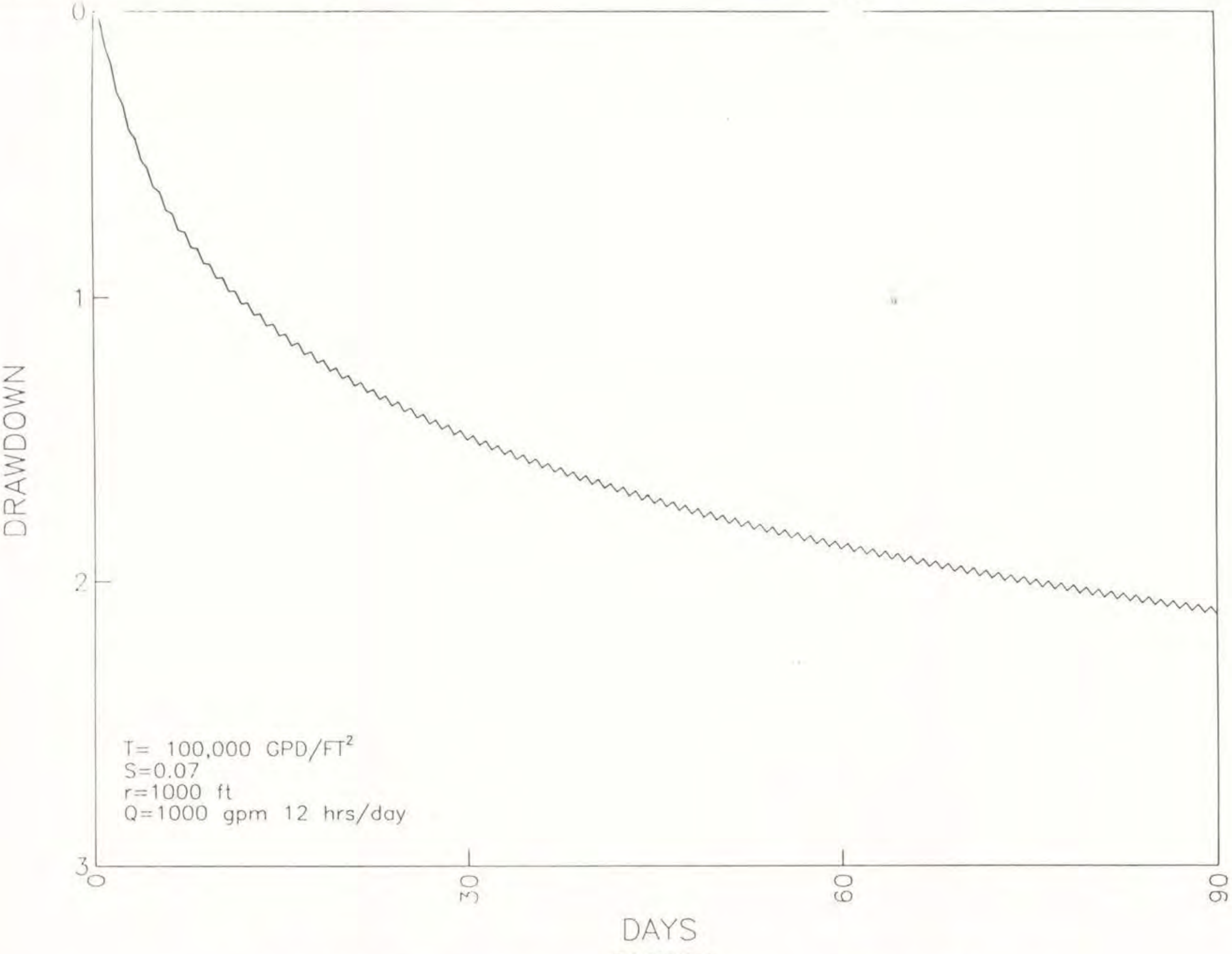


FIGURE E-7

THEIS ESTIMATE OF TIME-DRAWDOWN WITH 12-HOUR PUMPING CYCLES,UNCONFINED CONDITIONS

Appendix F

Confidence and Prediction Intervals

Ninety-five percent confidence intervals and 95 percent prediction intervals for each hydraulic conductivity zone are presented in the following graphs. Each graph includes a scattergram of simulated water levels plotted against measured water levels. The straight line plotted through the scattergram is the best-fit linear regression line.

Graphs are presented in pairs. The first graph of each pair includes curved lines bounding the best-fit line that represent the 95 percent confidence interval for that regression line. The second graph of each pair includes curved lines that represent the 95 percent prediction interval for the hydraulic conductivity zone.

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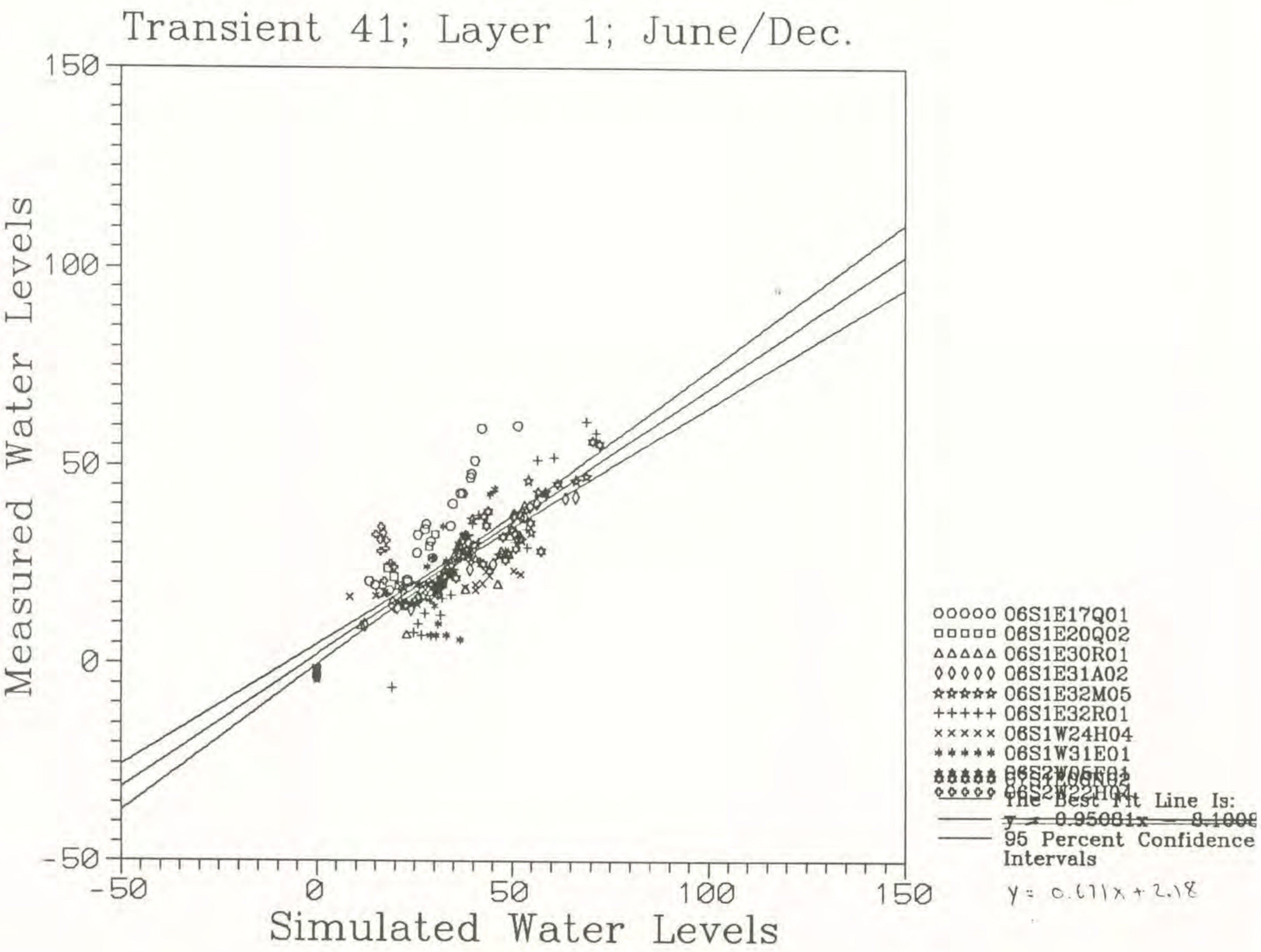
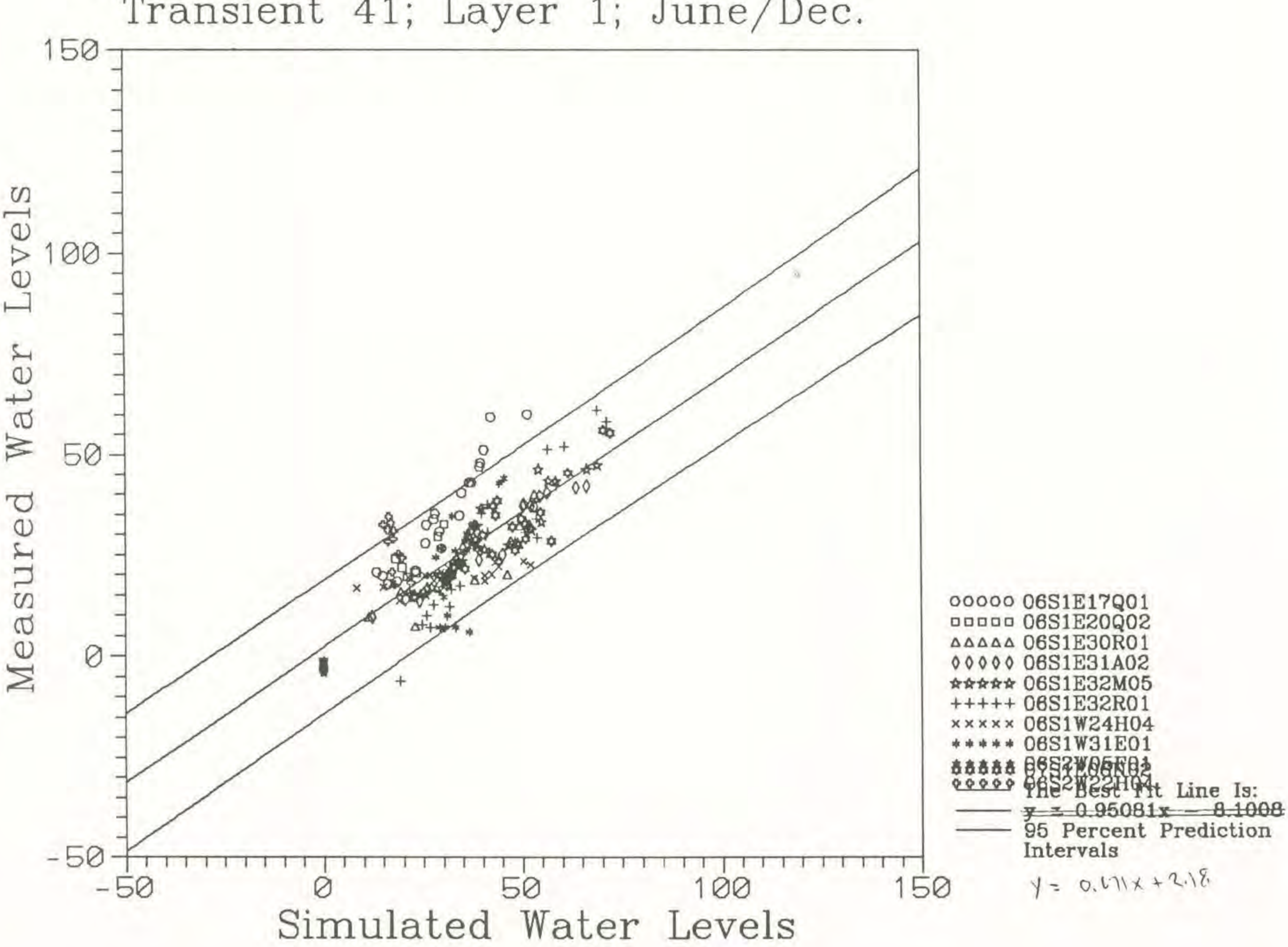
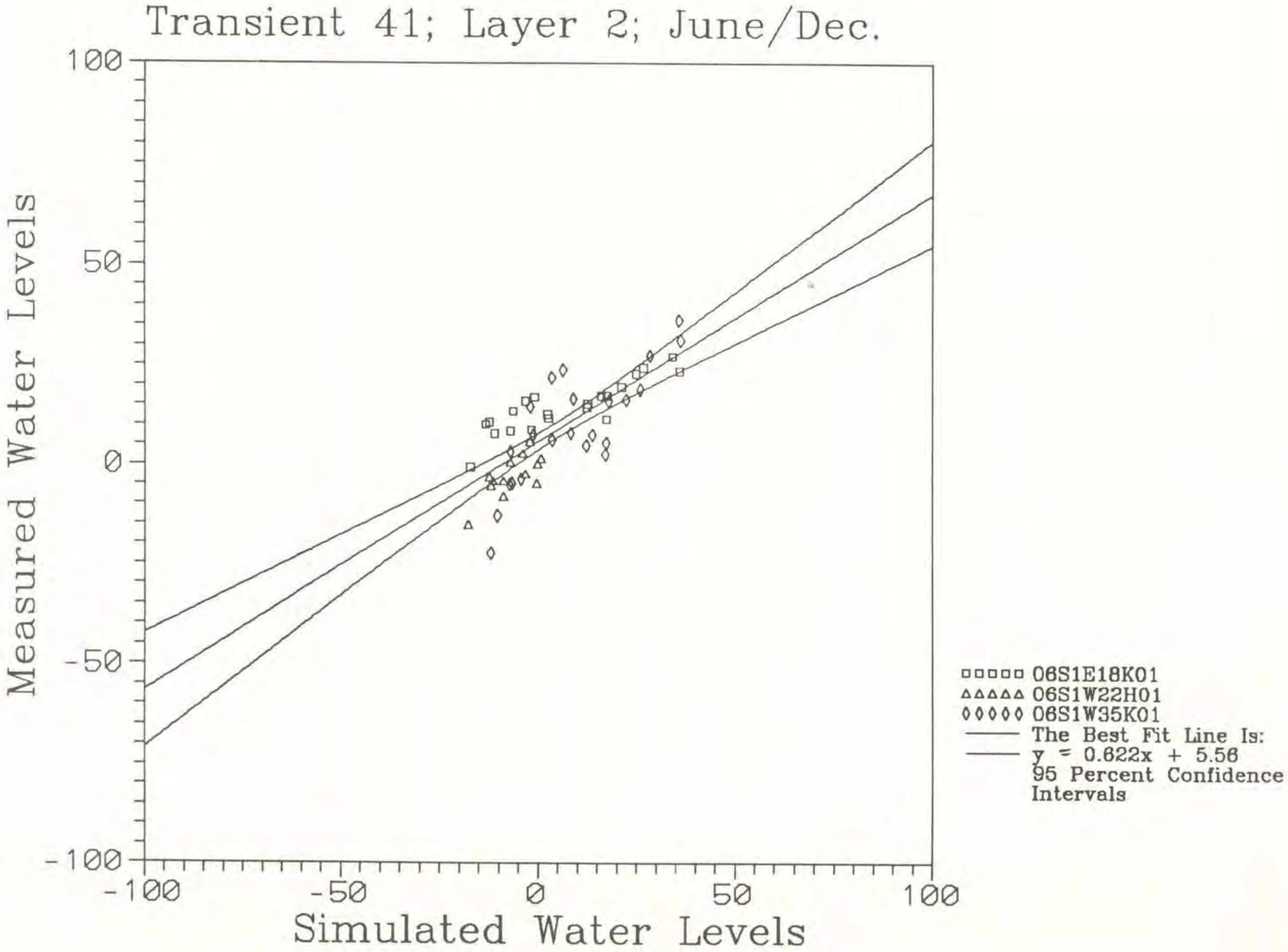
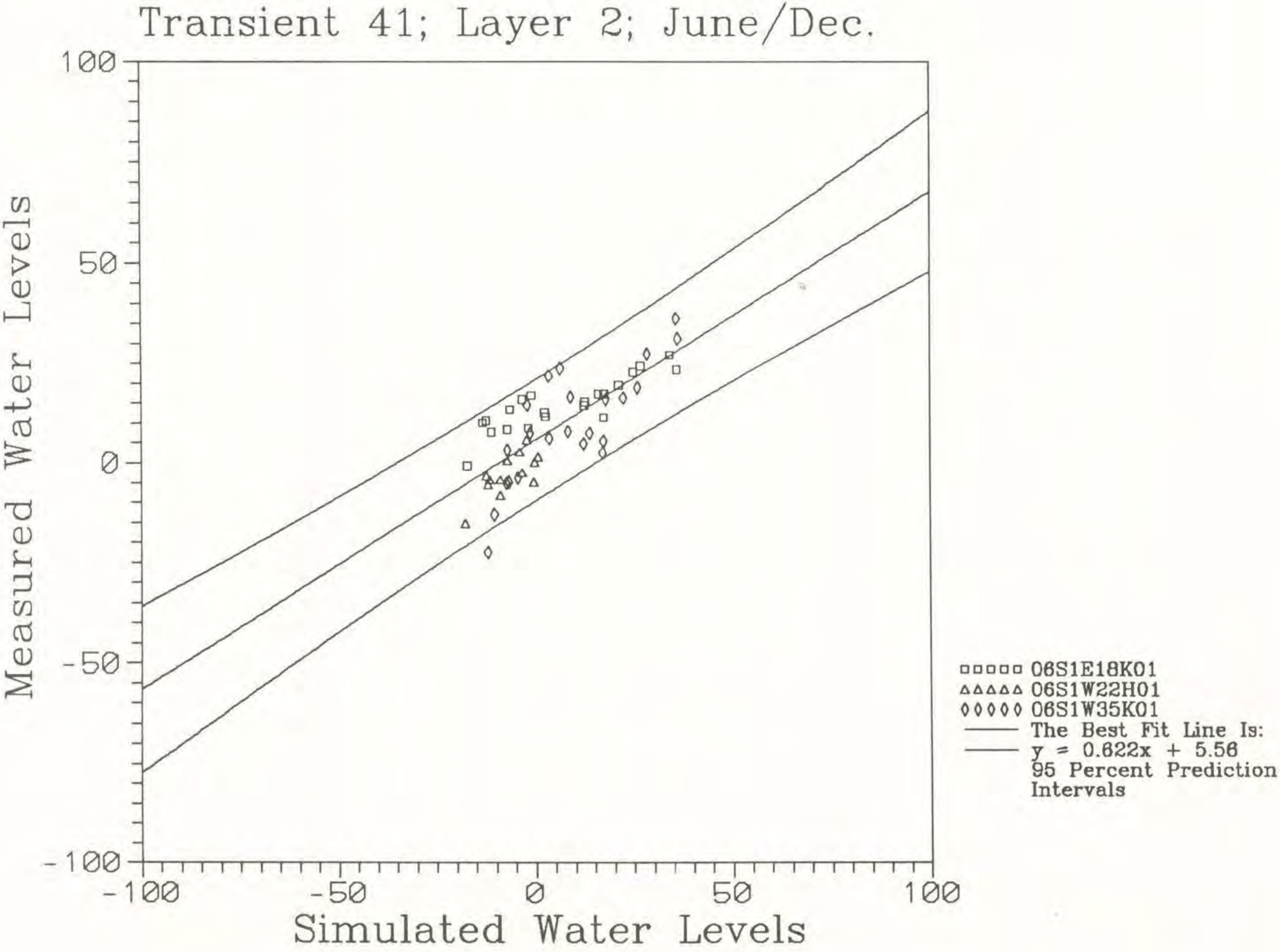

Transient 41; Layer 1; June/Dec.
Measured Water Levels
Simulated Water Levels
150
100
50
0
-50
-50
0
50
100
150
06S1E17Q01
06S1E20Q02
06S1E30R01
06S1E31A02
06S1E32M05
06S1E32R01
06S1W24H04
06S1W31E01
06S2W05F01
07S1E06N02
06S2W22H04
The Best Fit Line Is:
~~y = 0.95081x - 8.100~~
95 Percent Confidence Intervals

y = 0.671x + 2.18

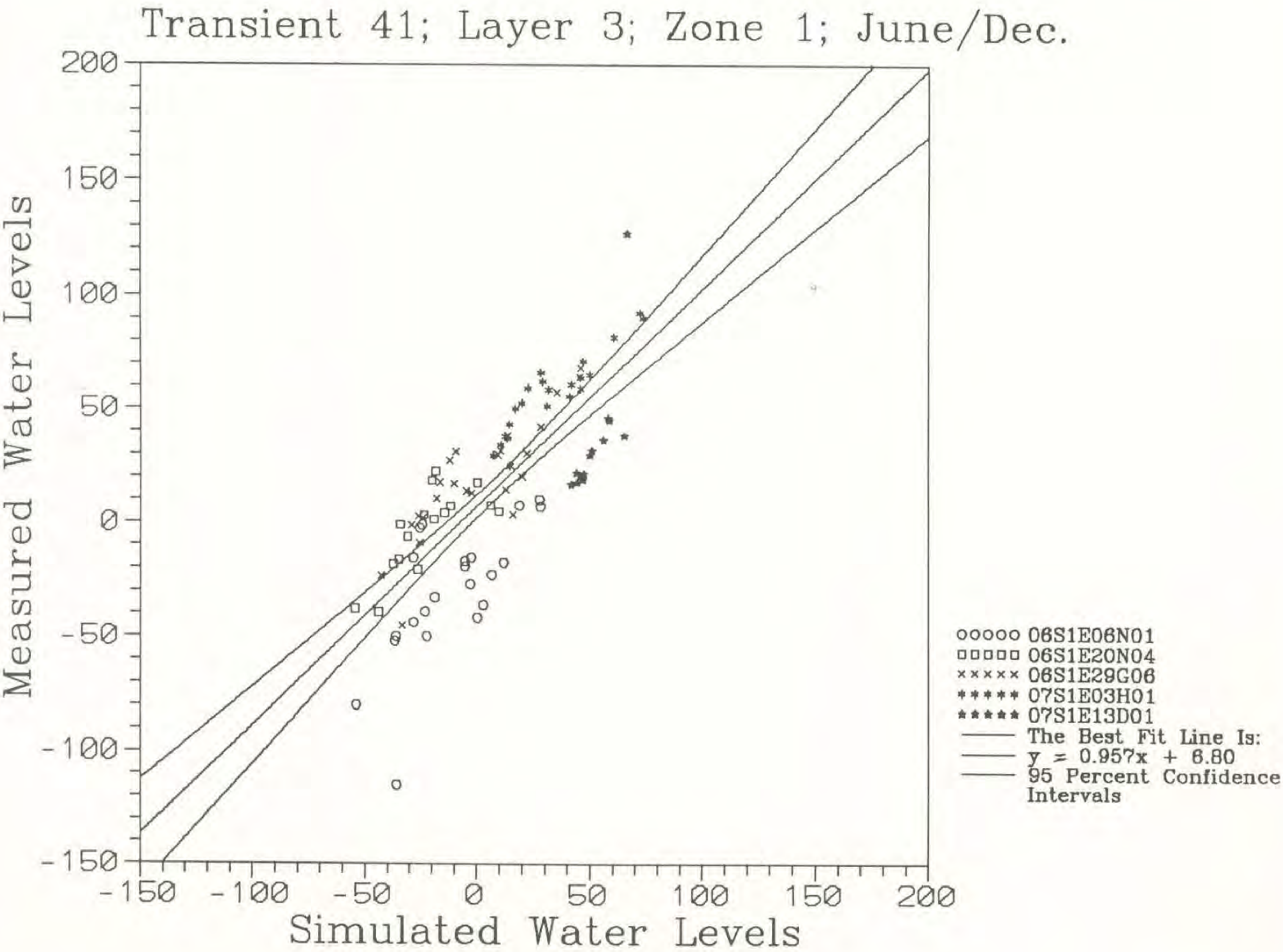

Transient 41; Layer 1; June/Dec.
Measured Water Levels
Simulated Water Levels
150
100
50
0
-50
-50
0
50
100
150
○○○○○ 06S1E17Q01
□□□□□ 06S1E20Q02
△△△△△ 06S1E30R01
◊◊◊◊◊ 06S1E31A02
☆☆☆☆☆ 06S1E32M05
+++++ 06S1E32R01
××××× 06S1W24H04
***** 06S1W31E01
06S2W05F01
07S1E06N02
06S2W22H04
The Best Fit Line Is:
~~y = 0.95081x - 8.1008~~
95 Percent Prediction Intervals

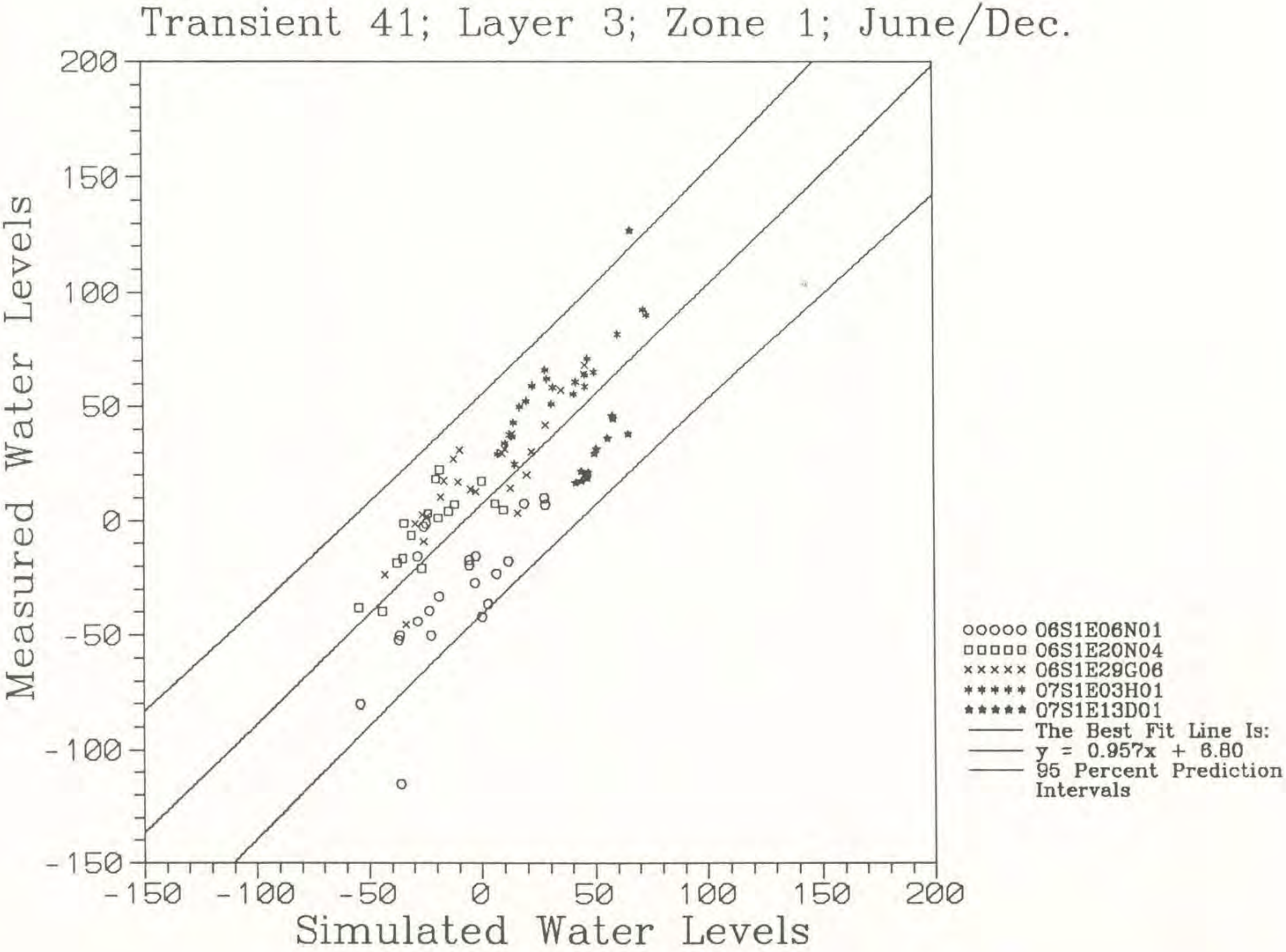
$y = 0.671x + 2.18$

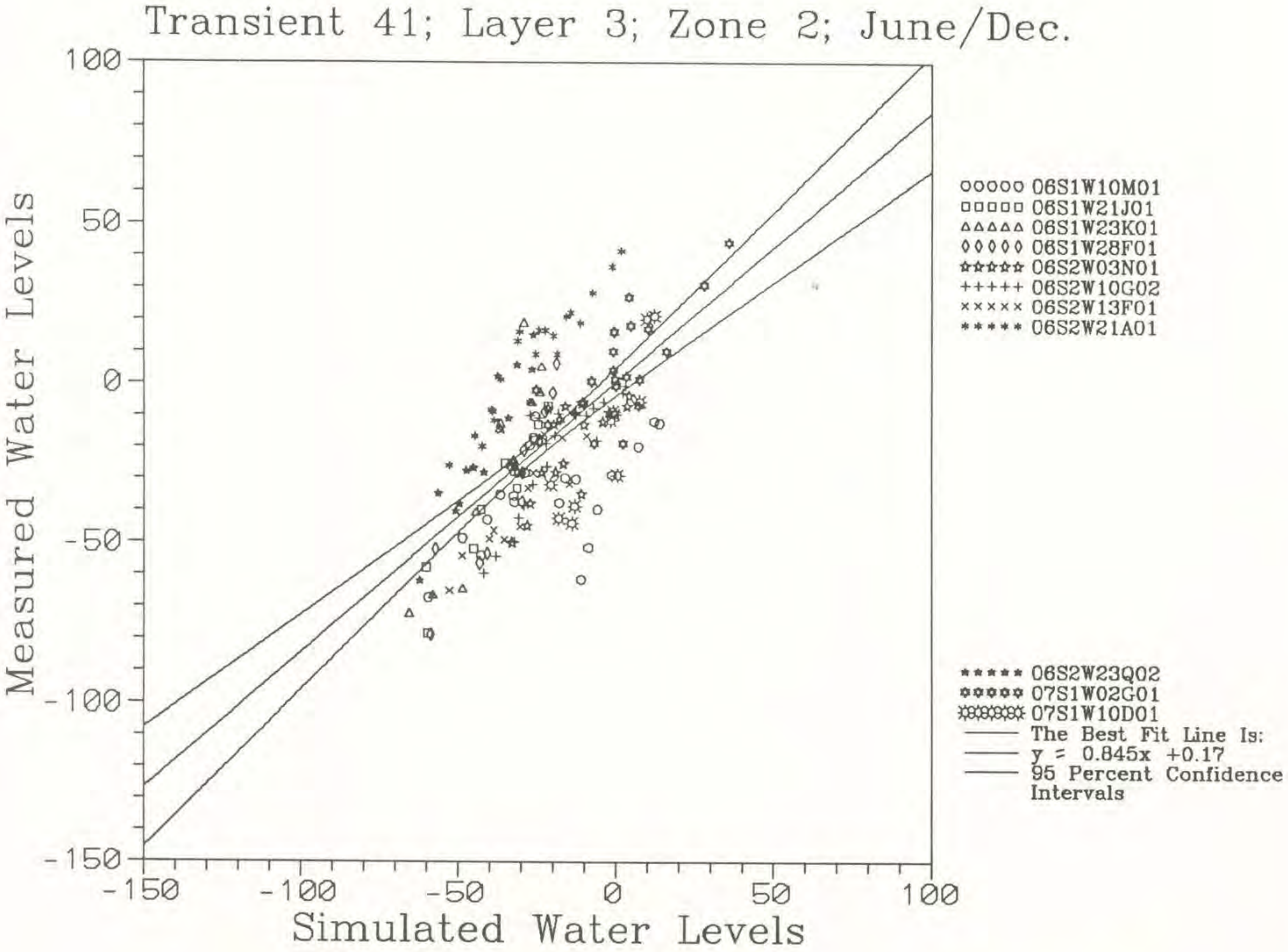

Transient 41; Layer 2; June/Dec.
Measured Water Levels
100
50
0
-50
-100
-100
-50
0
50
100
Simulated Water Levels
□□□□□ 06S1E18K01
△△△△△ 06S1W22H01
◊◊◊◊◊ 06S1W35K01
The Best Fit Line Is:
y = 0.622x + 5.56
95 Percent Confidence Intervals

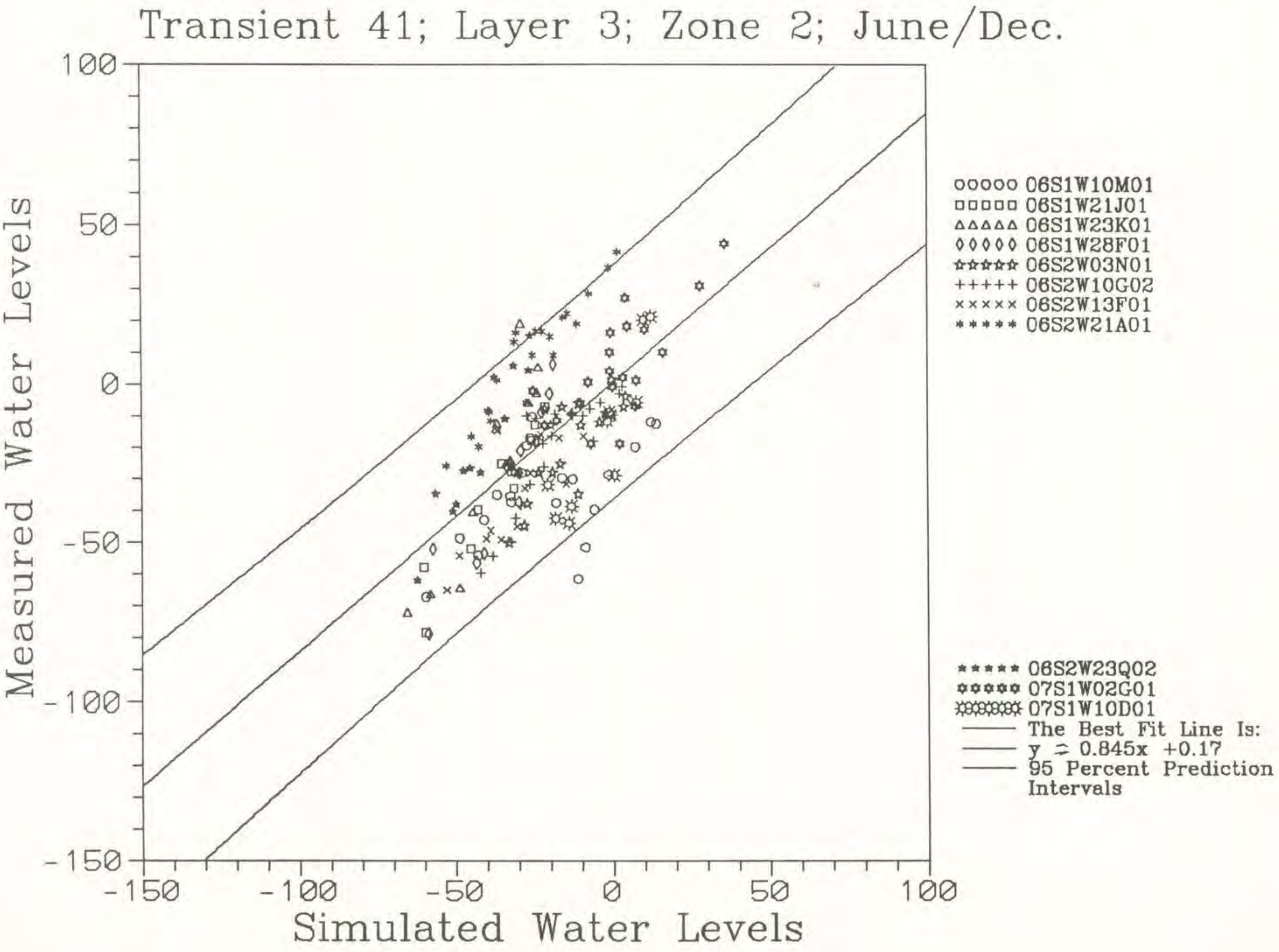


Transient 41; Layer 2; June/Dec.

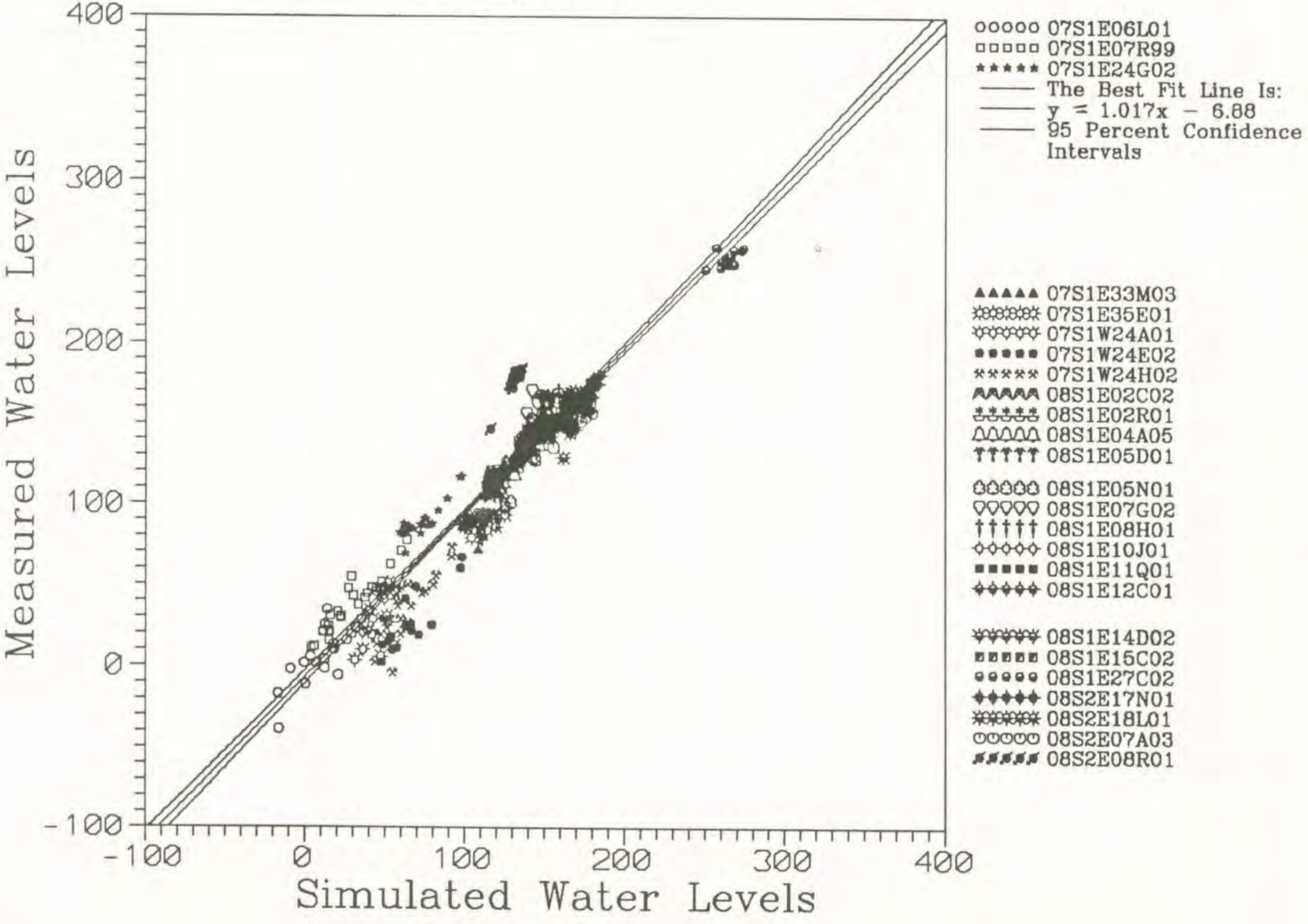

Transient 41; Layer 3; Zone 1; June/Dec.
Measured Water Levels
Simulated Water Levels
200
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
200
ooooo 06S1E06N01
▫▫▫▫▫ 06S1E20N04
××××× 06S1E29G06
***** 07S1E03H01
★★★★★ 07S1E13D01
The Best Fit Line Is:
y = 0.957x + 6.80
95 Percent Confidence
Intervals


Transient 41; Layer 3; Zone 1; June/Dec.
Measured Water Levels
200
150
100
50
0
-50
-100
-150
Simulated Water Levels
-150
-100
-50
0
50
100
150
200
ooooo 06S1E06N01
□□□□□ 06S1E20N04
××××× 06S1E29G06
***** 07S1E03H01
***** 07S1E13D01
The Best Fit Line Is:
y = 0.957x + 6.80
95 Percent Prediction Intervals

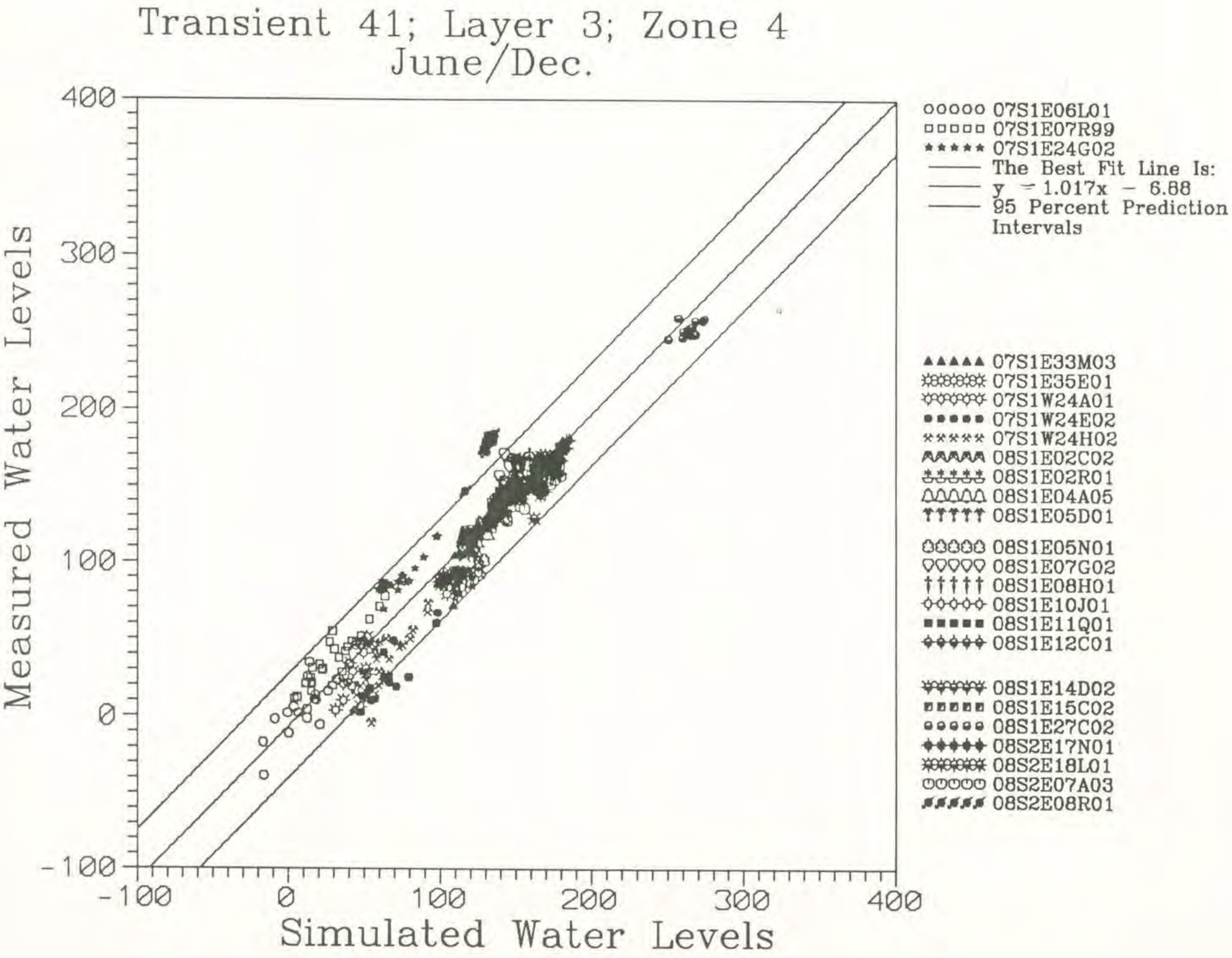

Transient 41; Layer 3; Zone 2; June/Dec.
Measured Water Levels
Simulated Water Levels
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
○○○○○ 06S1W10M01
□□□□□ 06S1W21J01
△△△△△ 06S1W23K01
◊◊◊◊◊ 06S1W28F01
☆☆☆☆☆ 06S2W03N01
+++++ 06S2W10G02
××××× 06S2W13F01
***** 06S2W21A01
***** 06S2W23Q02
✡✡✡✡✡ 07S1W02G01
✡✡✡✡✡ 07S1W10D01
The Best Fit Line Is:
y = 0.845x +0.17
95 Percent Confidence Intervals

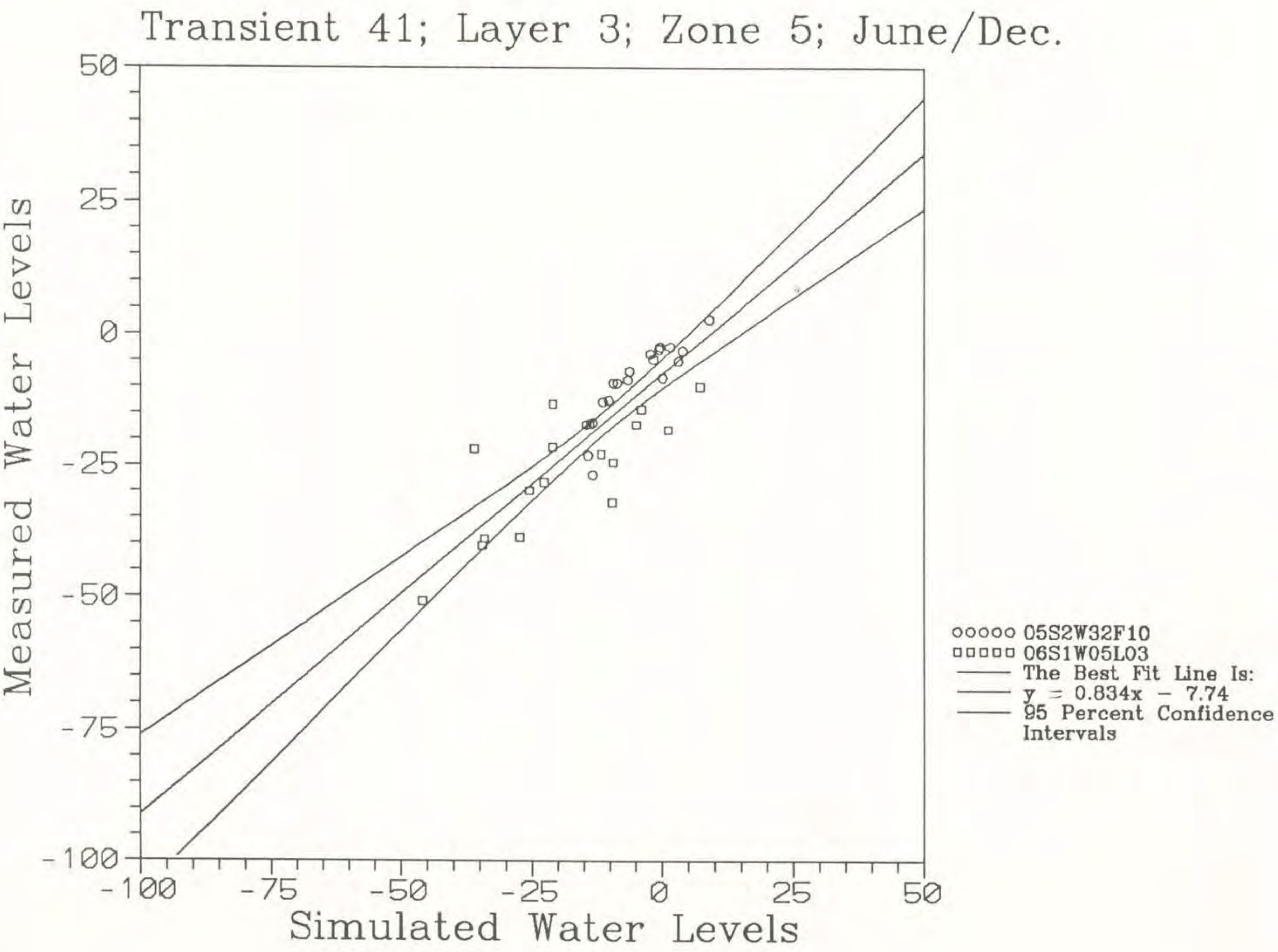


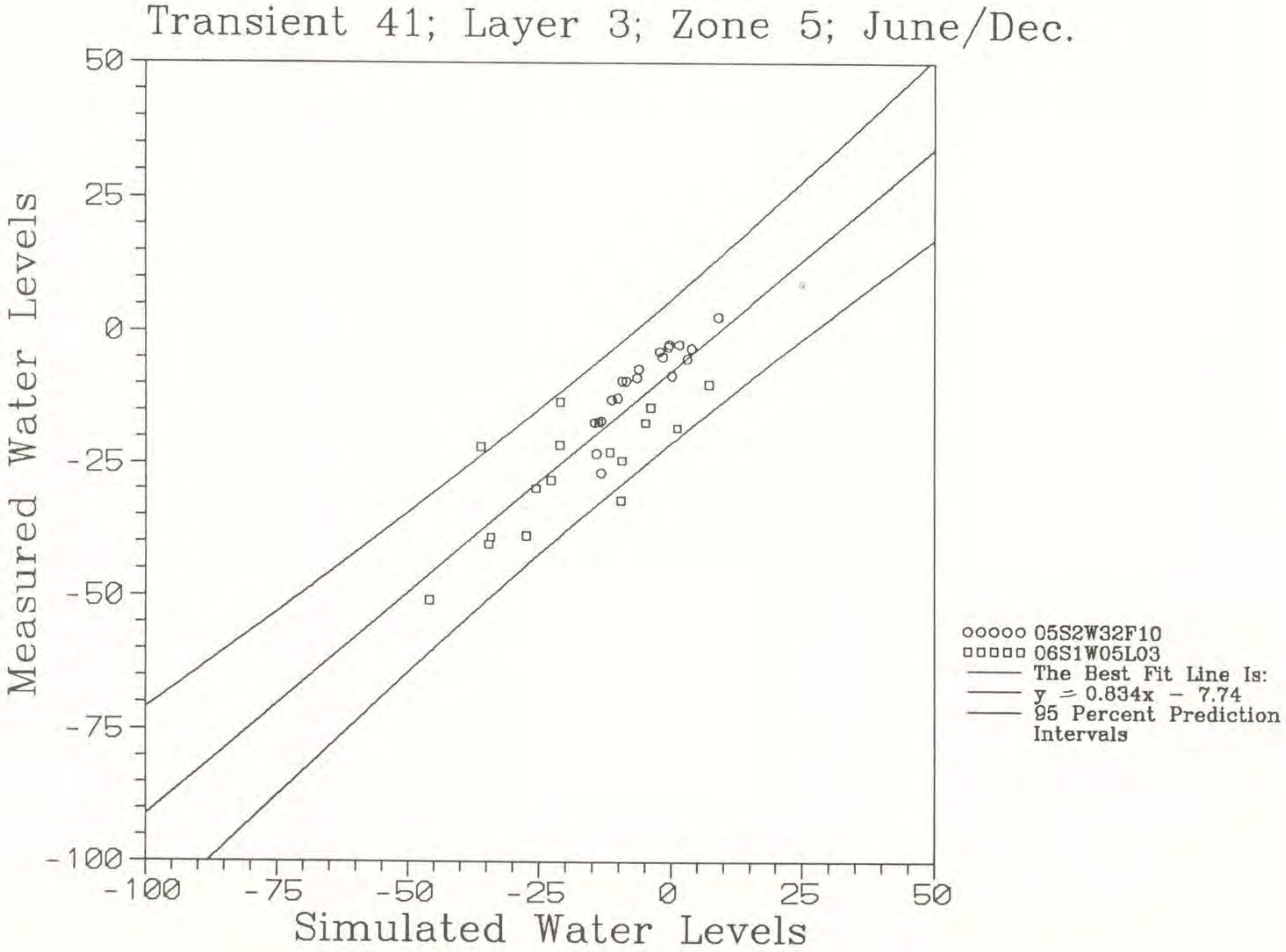
Transient 41; Layer 3; Zone 2; June/Dec.

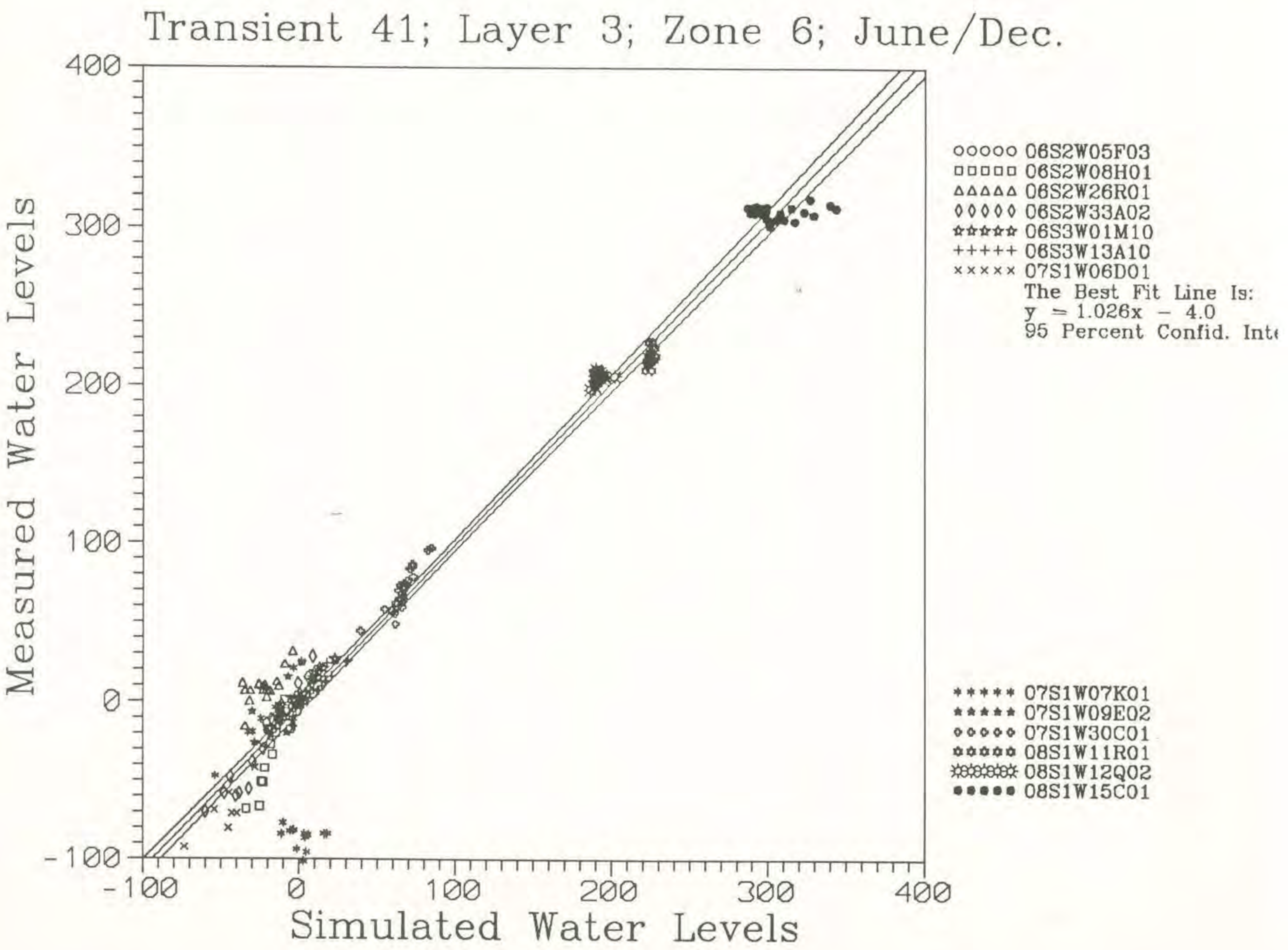


Transient 41; Layer 3; Zone 4
June/Dec.

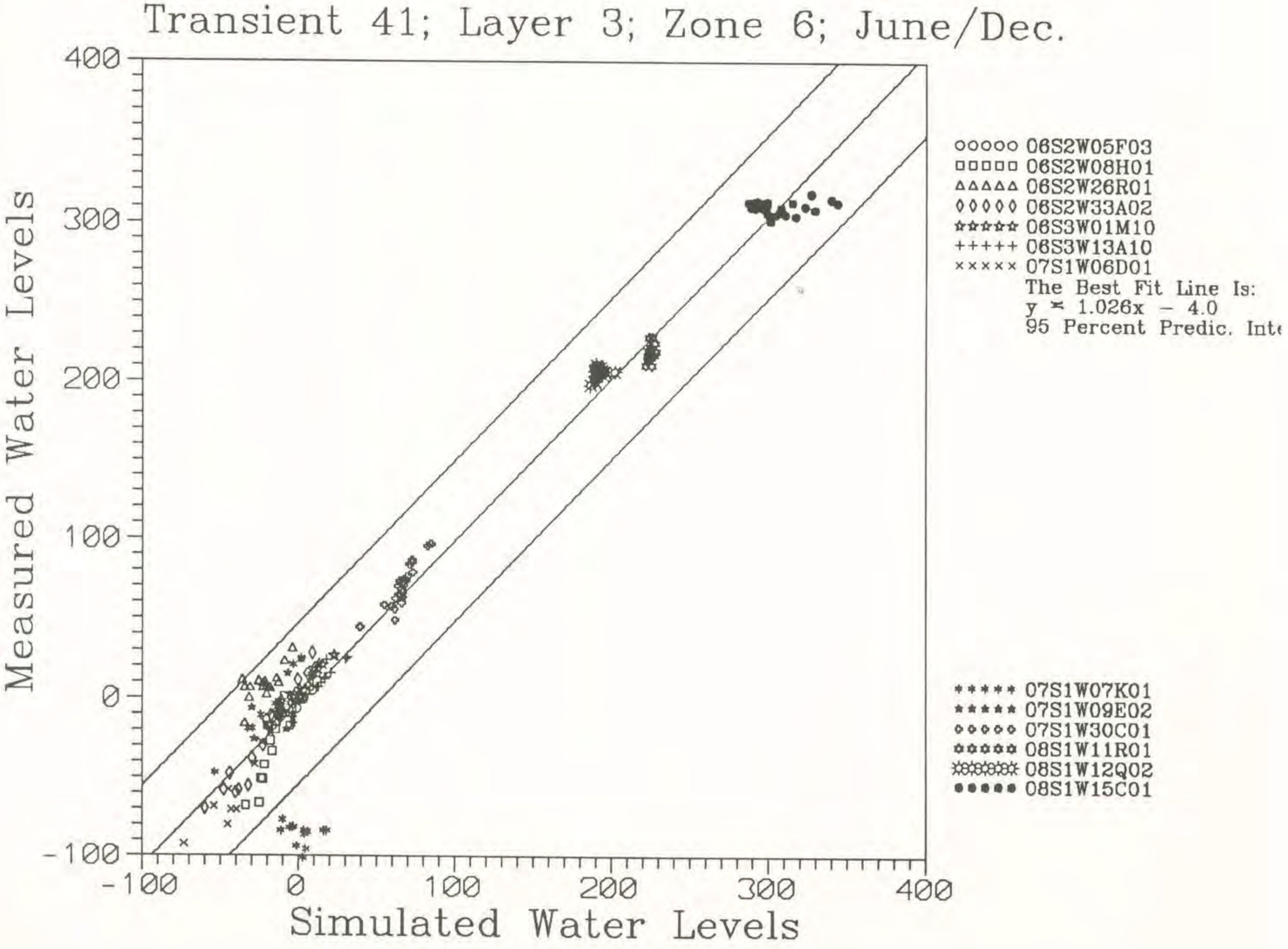

Transient 41; Layer 3; Zone 4
June/Dec.

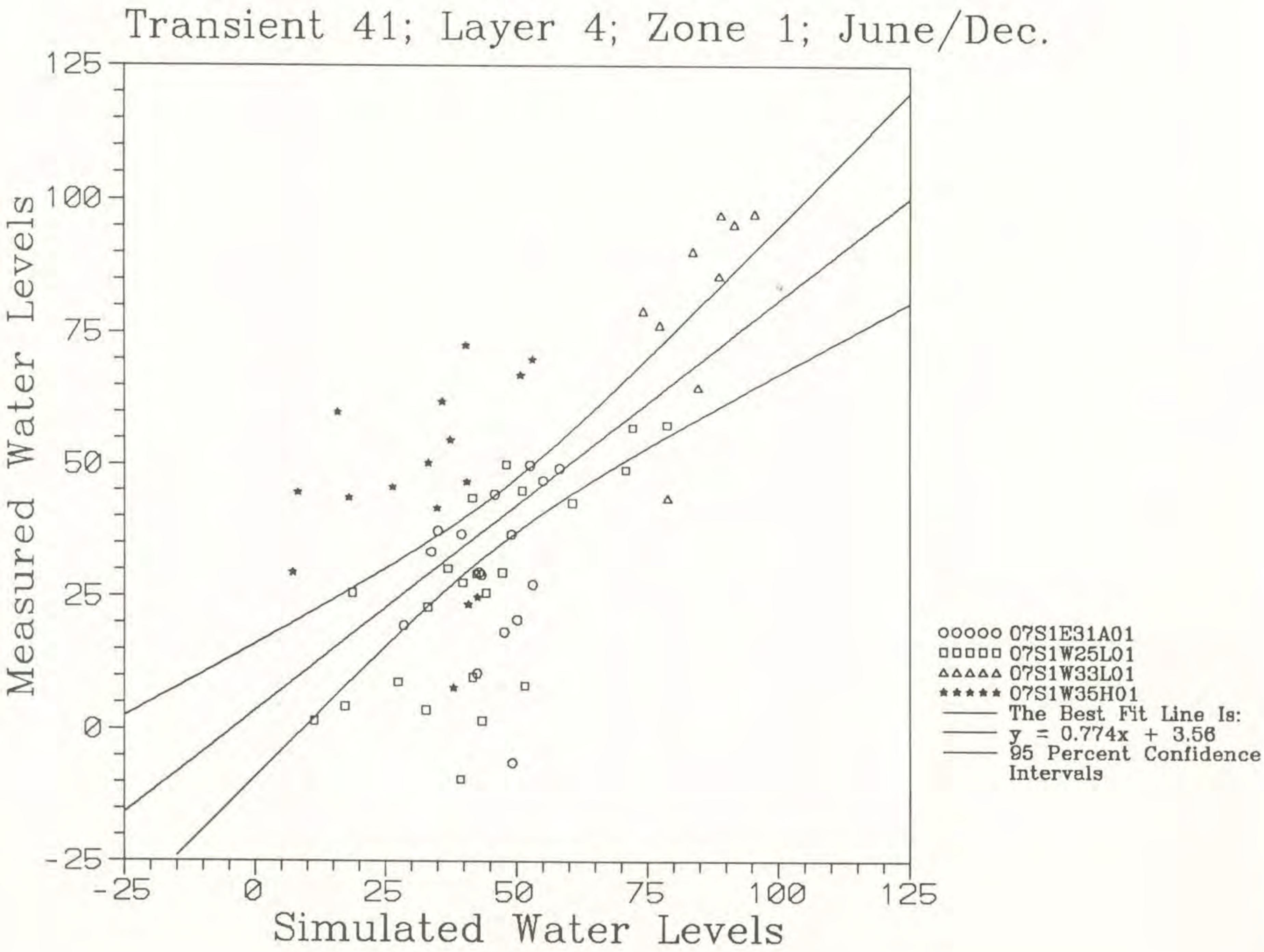

Transient 41; Layer 3; Zone 5; June/Dec.
Measured Water Levels
50
25
0
-25
-50
-75
-100
-100
-75
-50
-25
0
25
50
Simulated Water Levels
ooooo 05S2W32F10
□□□□□ 06S1W05L03
The Best Fit Line Is:
y = 0.834x - 7.74
95 Percent Confidence Intervals

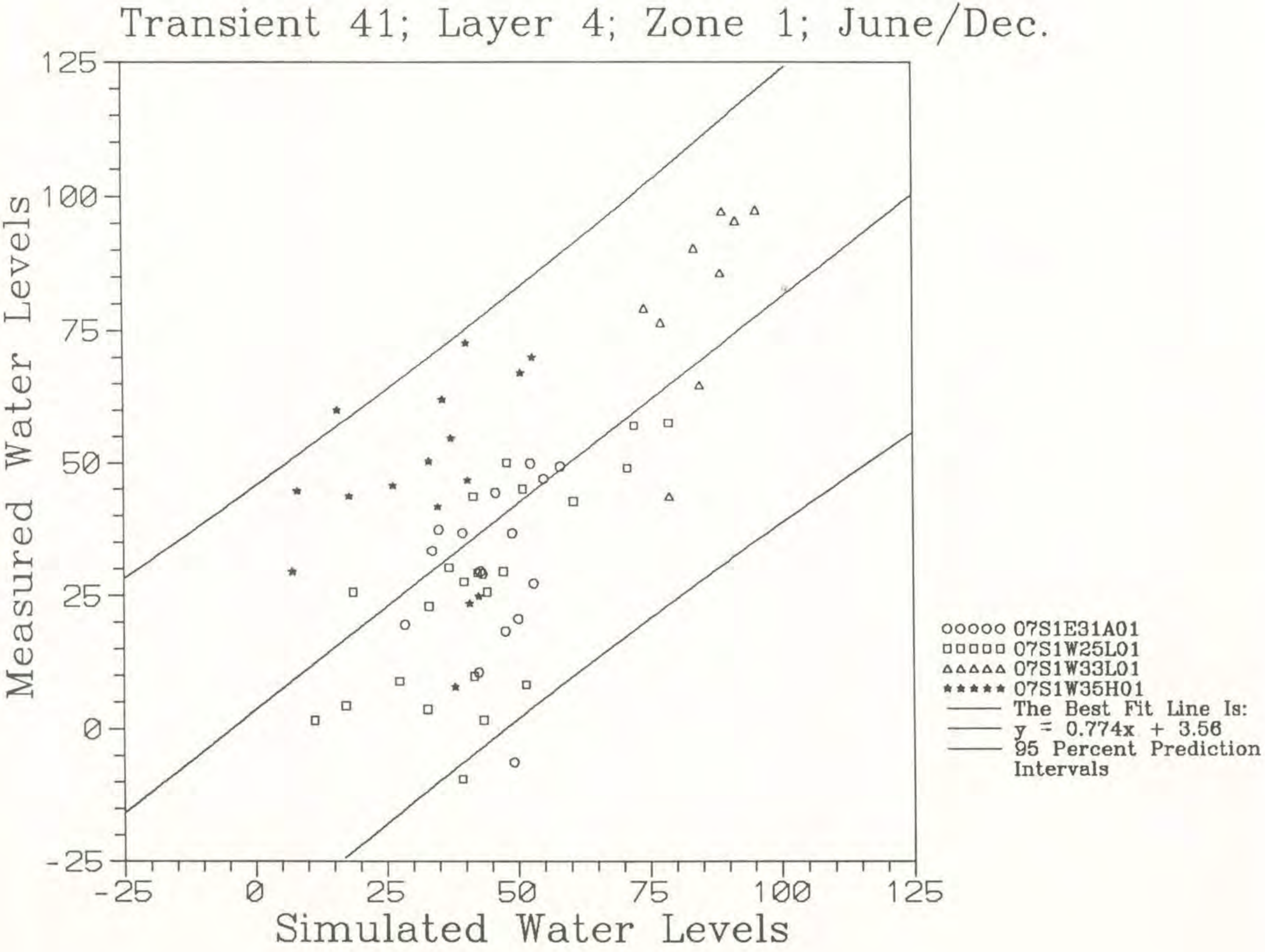

Transient 41; Layer 3; Zone 5; June/Dec.
Measured Water Levels
Simulated Water Levels
50
25
0
-25
-50
-75
-100
-100
-75
-50
-25
0
25
50
ooooo 05S2W32F10
□□□□□ 06S1W05L03
The Best Fit Line Is:
y = 0.834x - 7.74
95 Percent Prediction Intervals

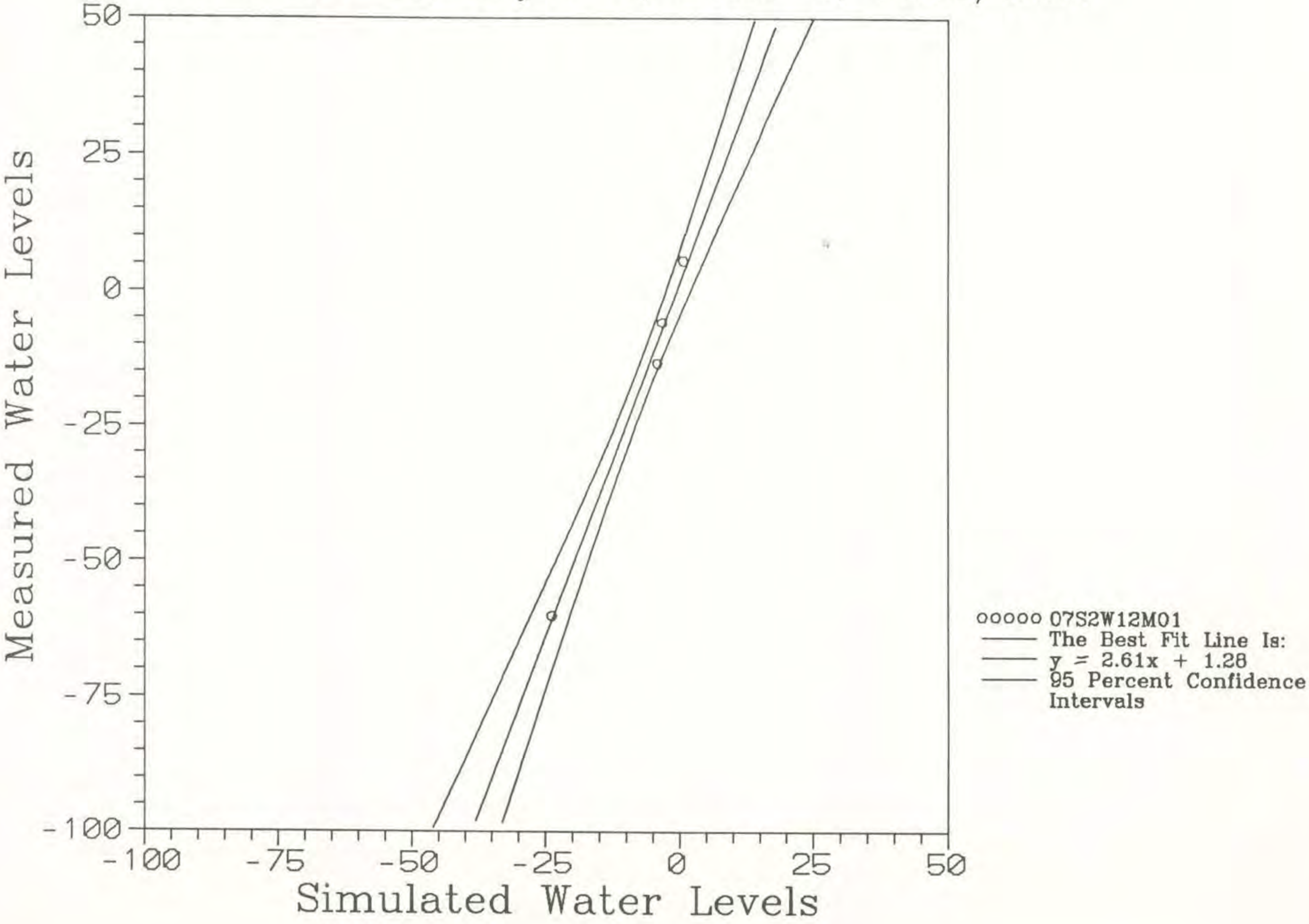


Transient 41; Layer 3; Zone 6; June/Dec.

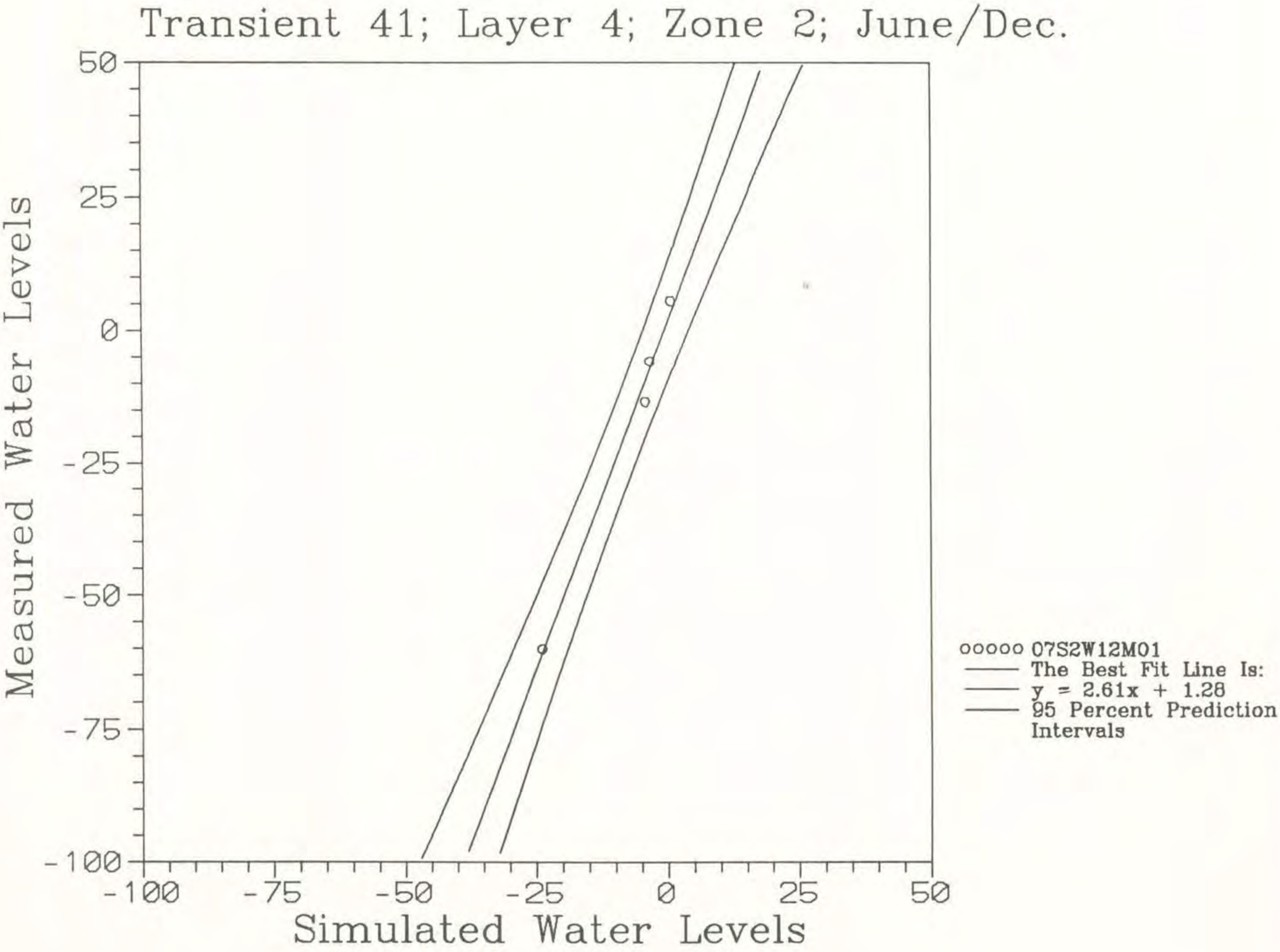

Transient 41; Layer 3; Zone 6; June/Dec.
Measured Water Levels
Simulated Water Levels
400
300
200
100
0
-100
-100
0
100
200
300
400
○○○○○ 06S2W05F03
□□□□□ 06S2W08H01
△△△△△ 06S2W26R01
◊◊◊◊◊ 06S2W33A02
☆☆☆☆☆ 06S3W01M10
+++++ 06S3W13A10
××××× 07S1W06D01
The Best Fit Line Is:
y = 1.026x - 4.0
95 Percent Predic. Int
***** 07S1W07K01
***** 07S1W09E02
◊◊◊◊◊ 07S1W30C01
✡✡✡✡✡ 08S1W11R01
✡✡✡✡✡ 08S1W12Q02
●●●●● 08S1W15C01

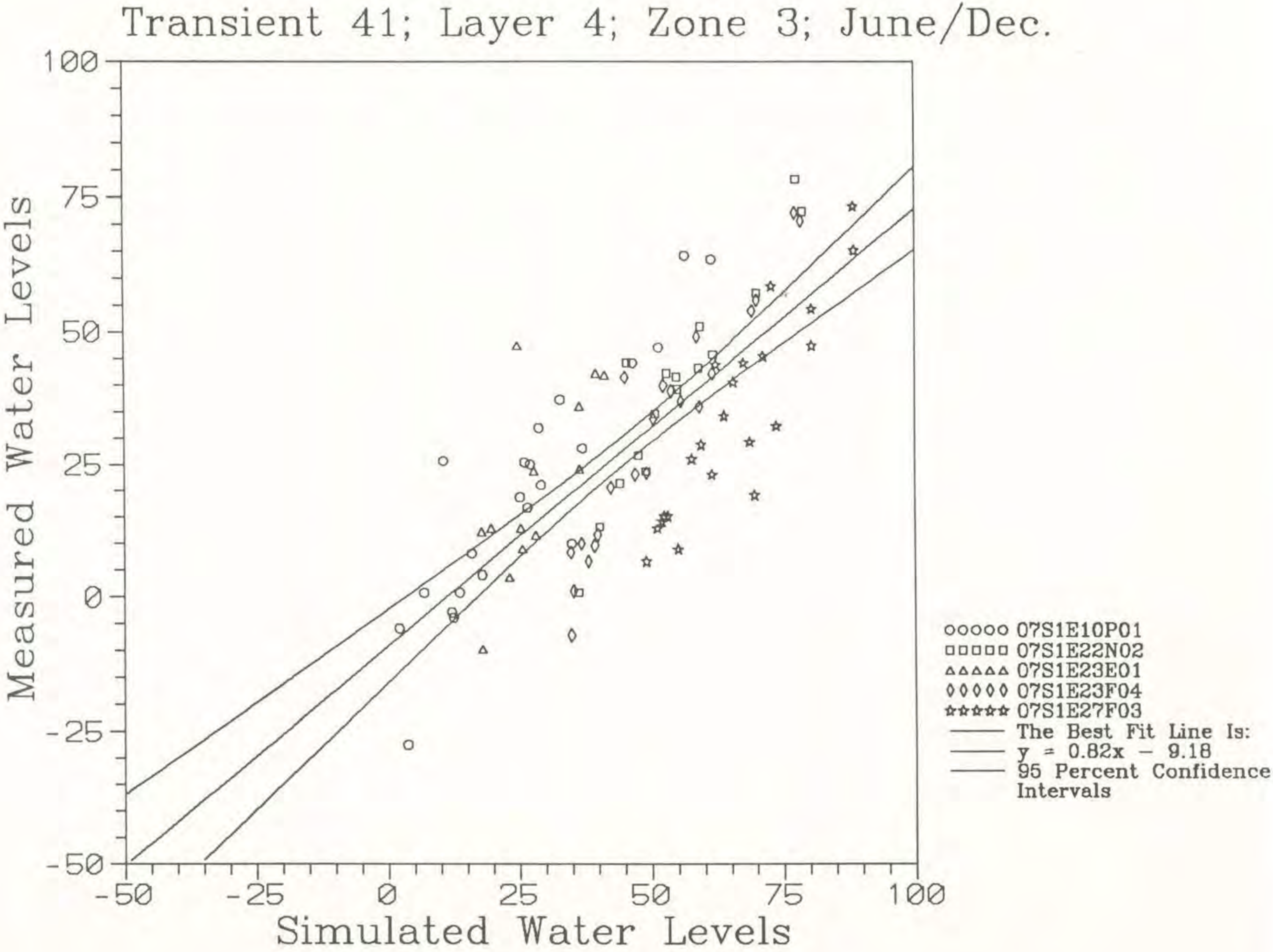

Transient 41; Layer 4; Zone 1; June/Dec.
Measured Water Levels
Simulated Water Levels
125
100
75
50
25
0
-25
-25
0
25
50
75
100
125
○○○○○ 07S1E31A01
□□□□□ 07S1W25L01
△△△△△ 07S1W33L01
★★★★★ 07S1W35H01
The Best Fit Line Is:
y = 0.774x + 3.56
95 Percent Confidence Intervals


Transient 41; Layer 4; Zone 1; June/Dec.
Measured Water Levels
Simulated Water Levels
125
100
75
50
25
0
-25
-25
0
25
50
75
100
125
○○○○○ 07S1E31A01
□□□□□ 07S1W25L01
△△△△△ 07S1W33L01
★★★★★ 07S1W35H01
The Best Fit Line Is:
y = 0.774x + 3.56
95 Percent Prediction Intervals

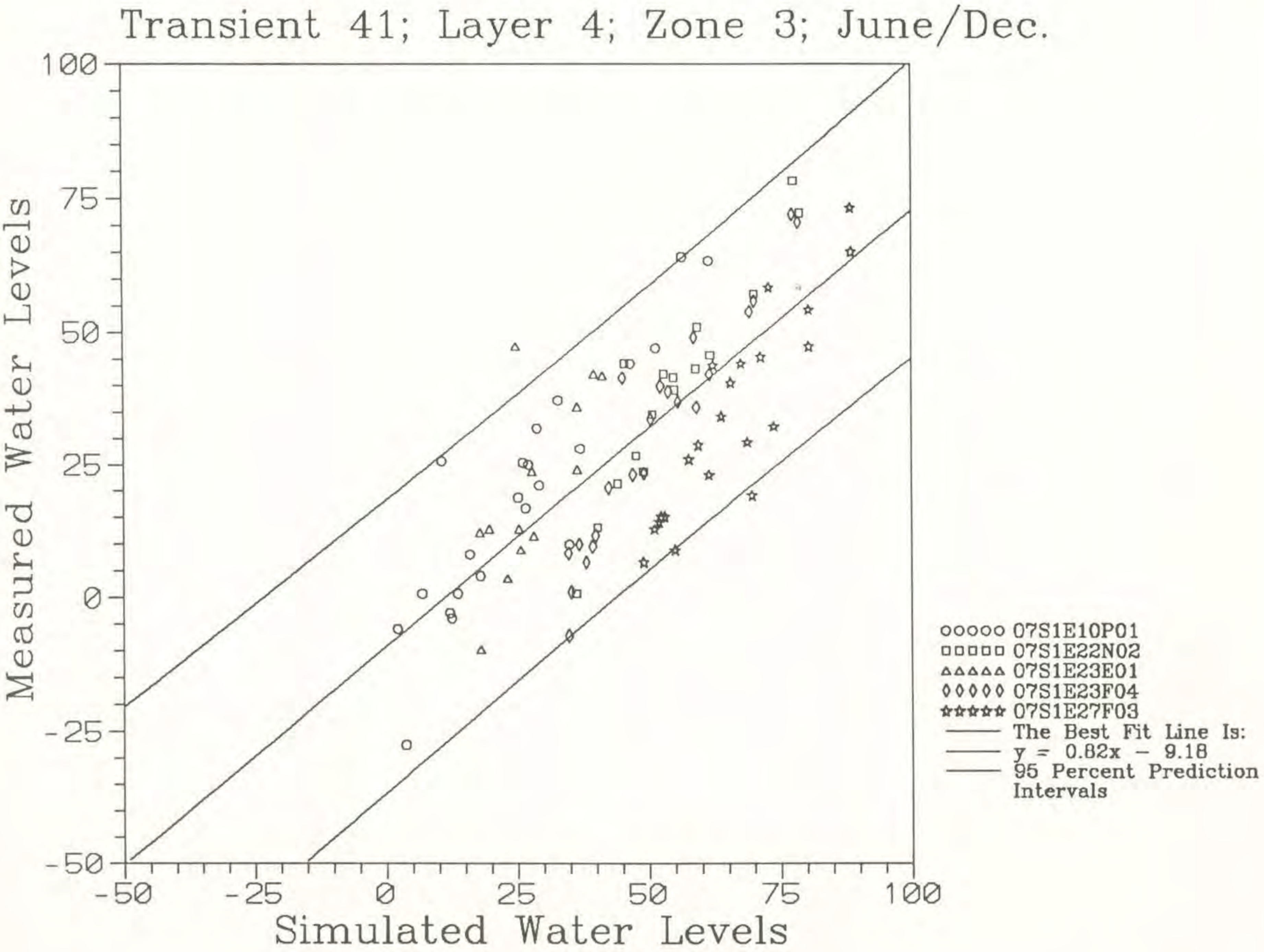


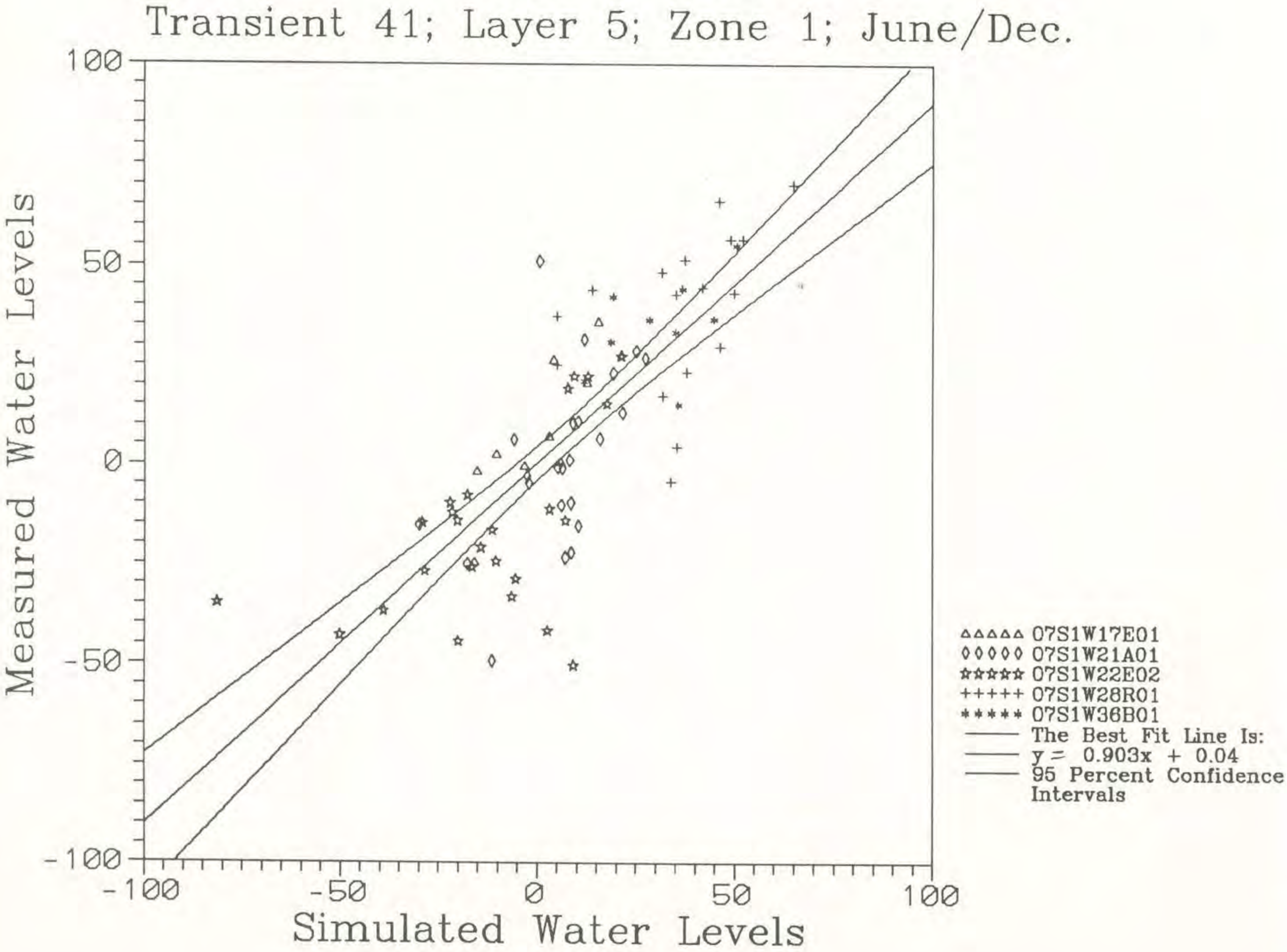
Transient 41; Layer 4; Zone 2; June/Dec.


Transient 41; Layer 4; Zone 2; June/Dec.
Measured Water Levels
Simulated Water Levels
50
25
0
-25
-50
-75
-100
-100
-75
-50
-25
0
25
50
ooooo 07S2W12M01
The Best Fit Line Is:
y = 2.61x + 1.28
95 Percent Prediction Intervals

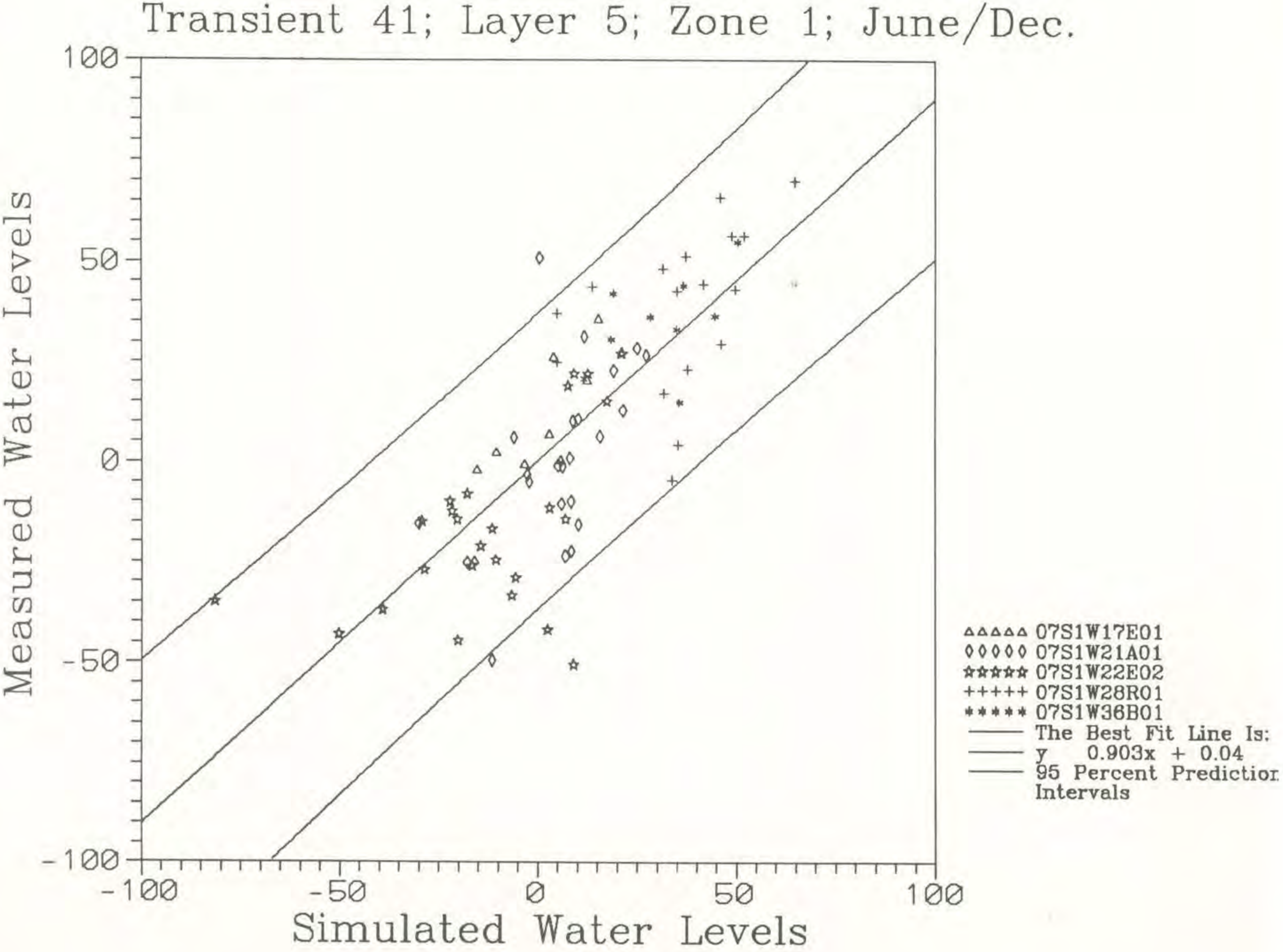


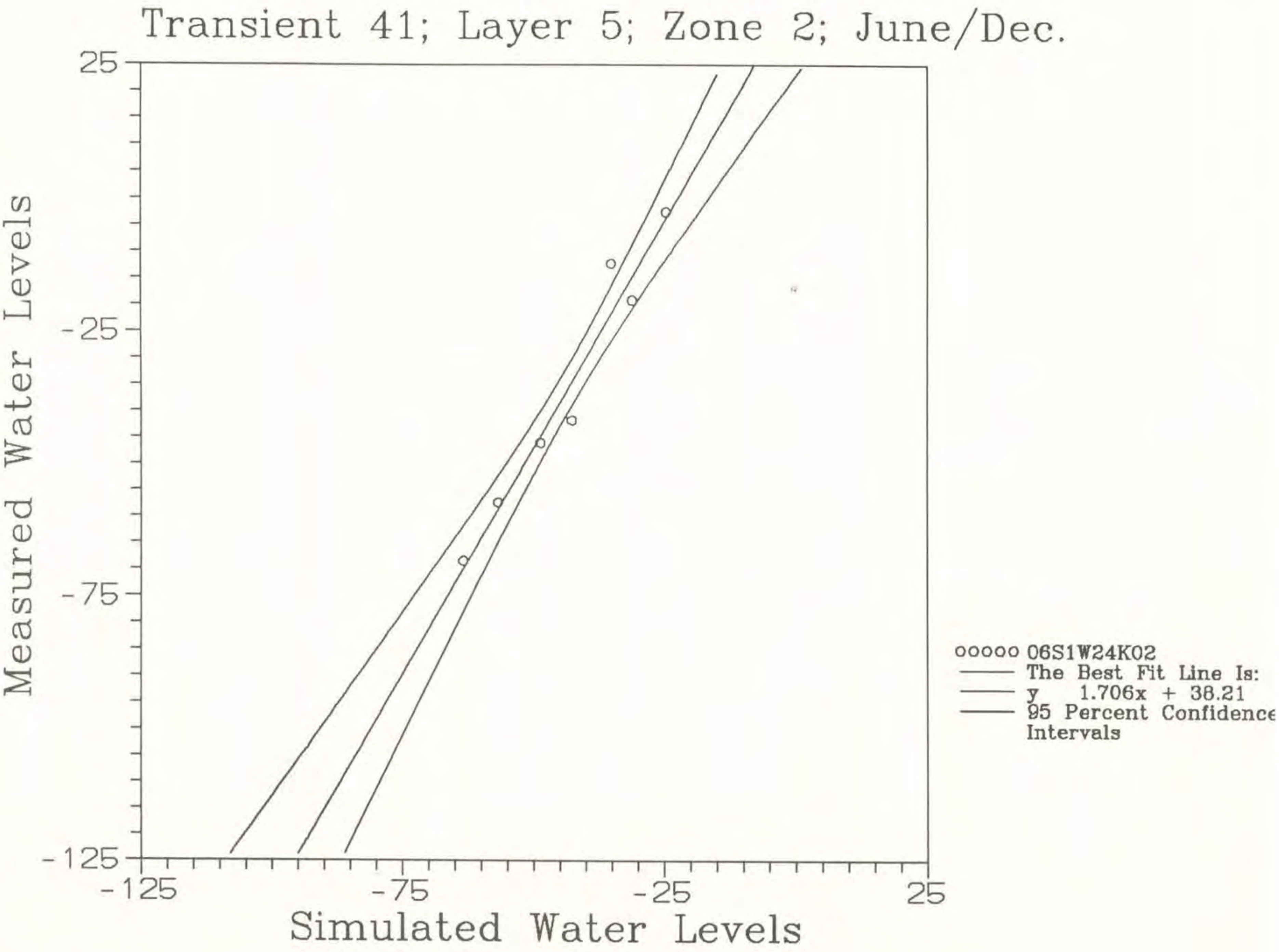
Transient 41; Layer 4; Zone 3; June/Dec.

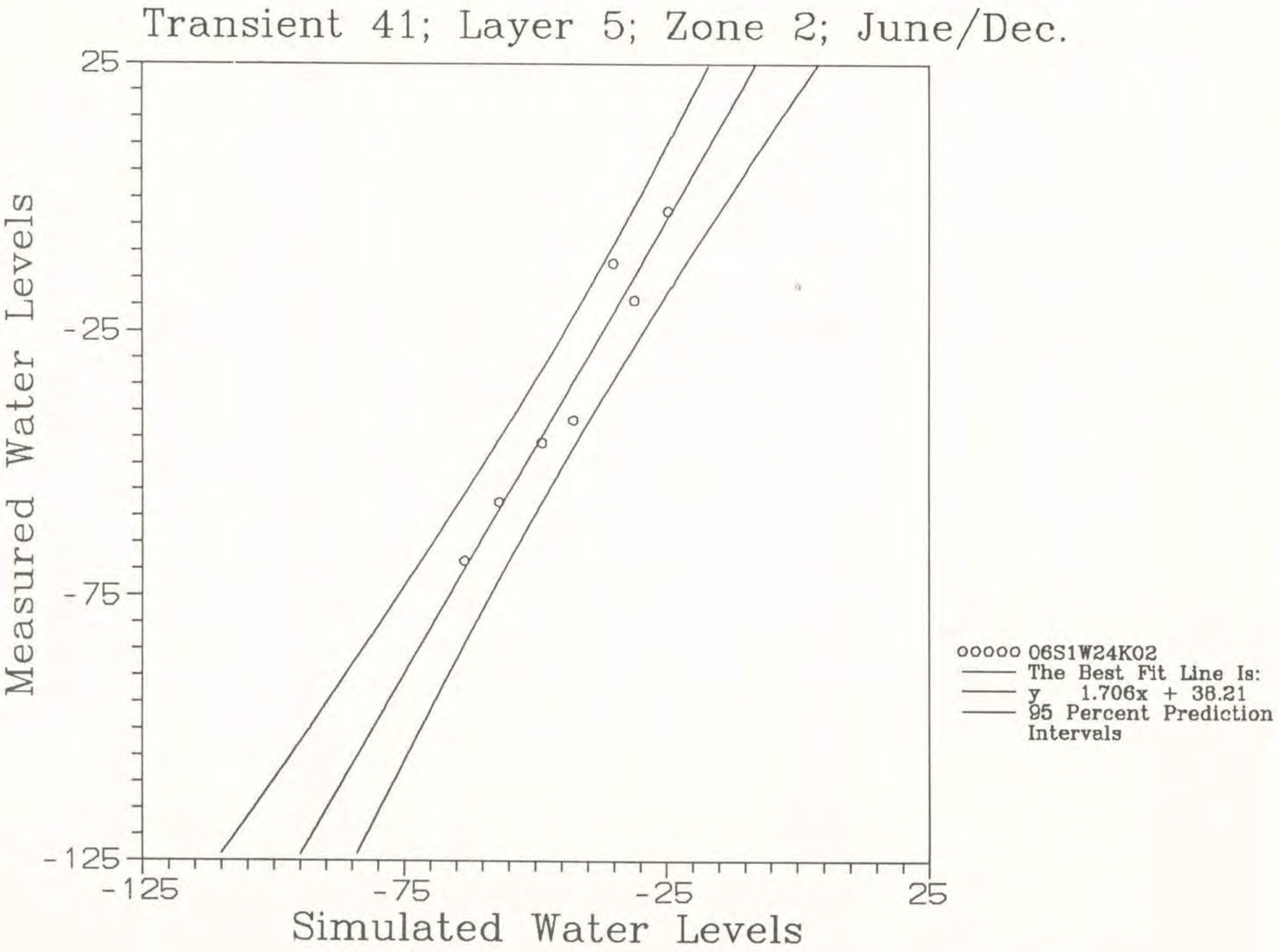

Transient 41; Layer 4; Zone 3; June/Dec.
Measured Water Levels
Simulated Water Levels
100
75
50
25
0
-25
-50
-50
-25
0
25
50
75
100
ooooo 07S1E10P01
□□□□□ 07S1E22N02
△△△△△ 07S1E23E01
◊◊◊◊◊ 07S1E23F04
☆☆☆☆☆ 07S1E27F03
The Best Fit Line Is:
y = 0.82x − 9.18
95 Percent Prediction Intervals

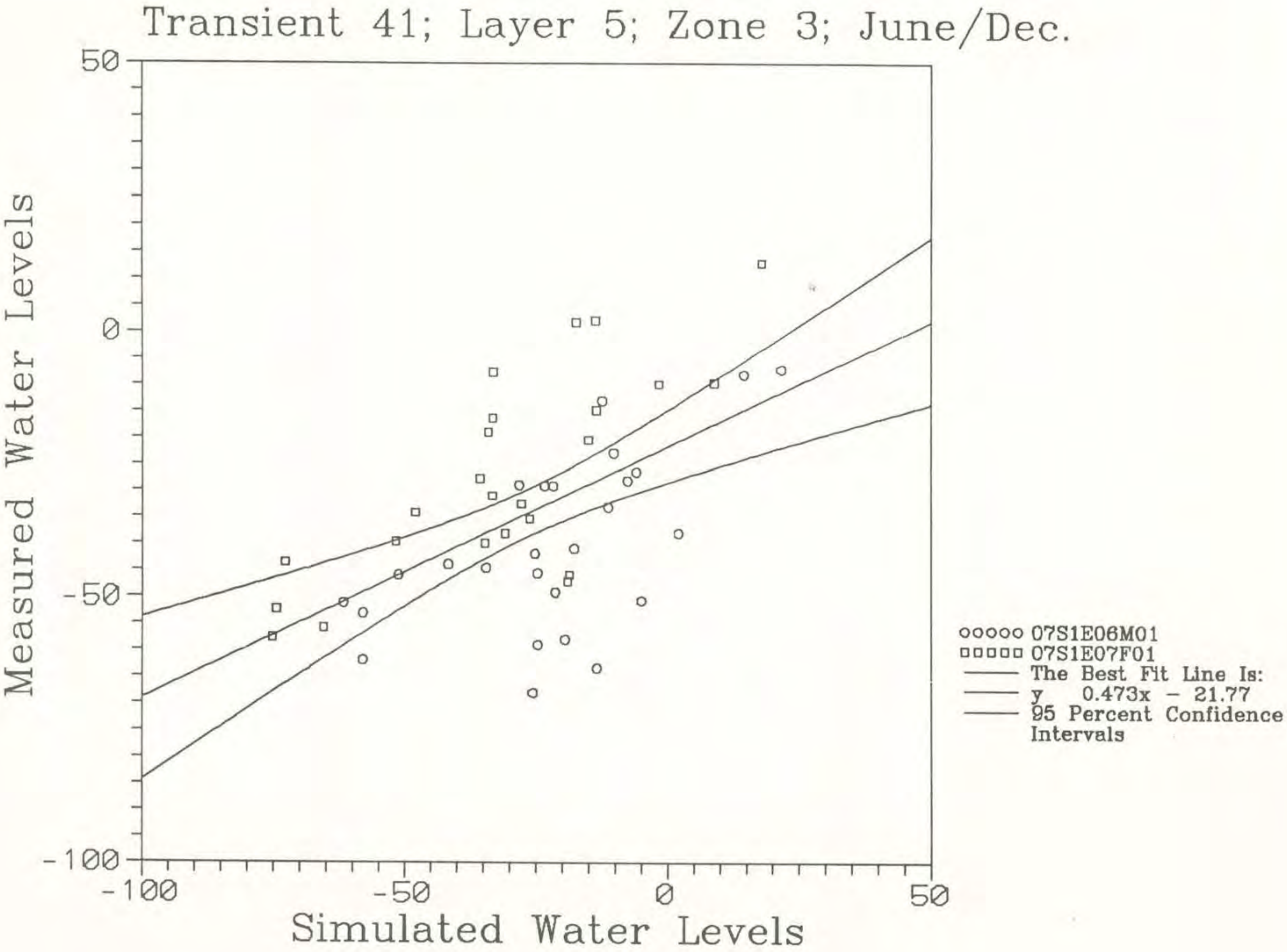


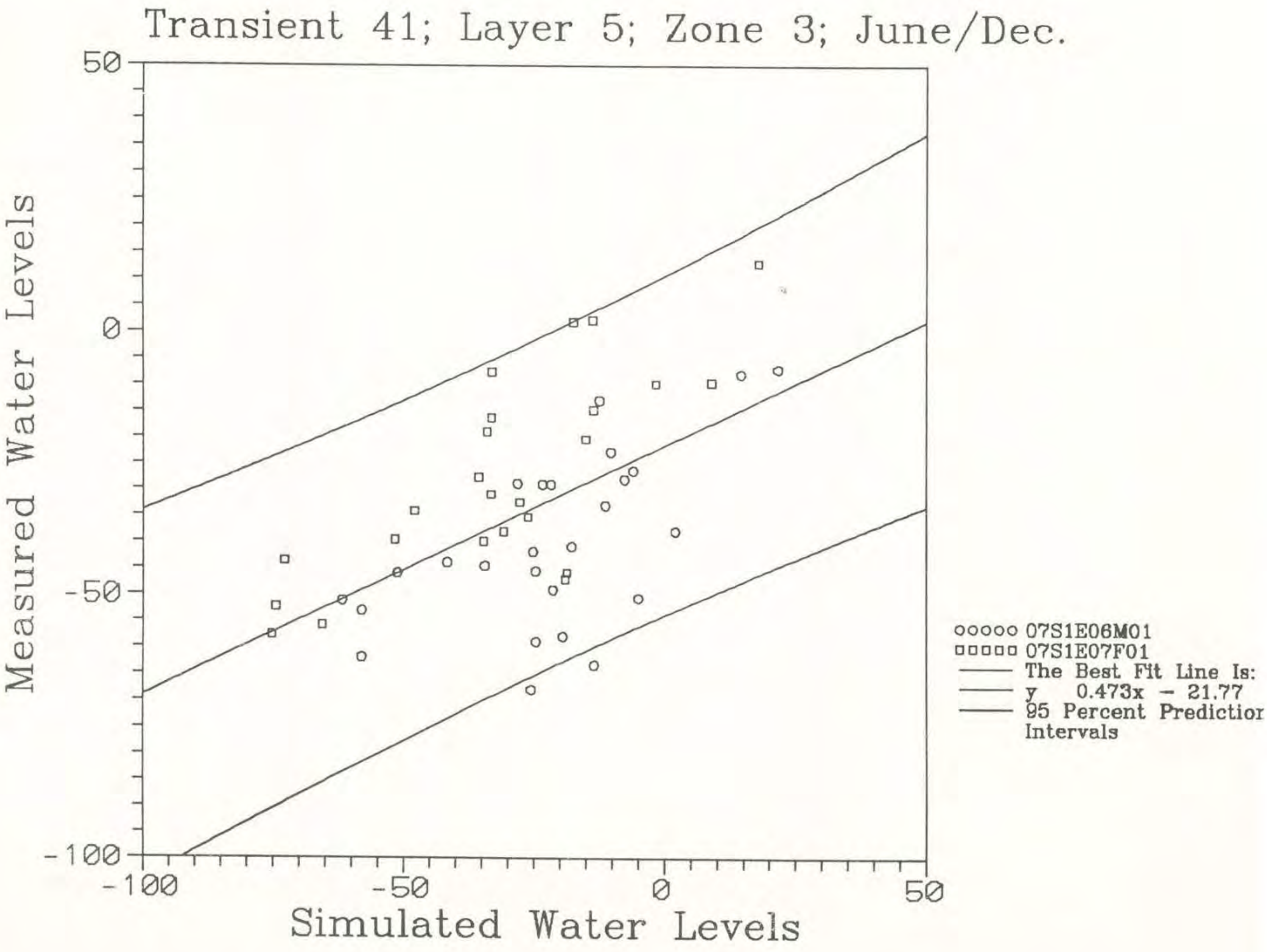
Transient 41; Layer 5; Zone 1; June/Dec.
Measured Water Levels
Simulated Water Levels
100
50
0
-50
-100
-100
-50
0
50
100
△△△△△ 07S1W17E01
◊◊◊◊◊ 07S1W21A01
☆☆☆☆☆ 07S1W22E02
+++++ 07S1W28R01
***** 07S1W36B01
The Best Fit Line Is:
y = 0.903x + 0.04
95 Percent Confidence Intervals


Transient 41; Layer 5; Zone 1; June/Dec.
Measured Water Levels
Simulated Water Levels
100
50
0
-50
-100
-100
-50
0
50
100
△△△△△ 07S1W17E01
◊◊◊◊◊ 07S1W21A01
☆☆☆☆☆ 07S1W22E02
+++++ 07S1W28R01
***** 07S1W36B01
The Best Fit Line Is:
y 0.903x + 0.04
95 Percent Predictior
Intervals


Transient 41; Layer 5; Zone 2; June/Dec.
Measured Water Levels
25
-25
-75
-125
Simulated Water Levels
-125
-75
-25
25
ooooo 06S1W24K02
The Best Fit Line Is:
y 1.706x + 38.21
95 Percent Confidence
Intervals


Transient 41; Layer 5; Zone 2; June/Dec.
Measured Water Levels
Simulated Water Levels
25
-25
-75
-125
-125
-75
-25
25
ooooo 06S1W24K02
The Best Fit Line Is:
y 1.706x + 38.21
95 Percent Prediction Intervals


Transient 41; Layer 5; Zone 3; June/Dec.
Measured Water Levels
50
0
-50
-100
Simulated Water Levels
-100
-50
0
50
ooooo 07S1E06M01
□□□□□ 07S1E07F01
The Best Fit Line Is:
y 0.473x - 21.77
95 Percent Confidence Intervals


Transient 41; Layer 5; Zone 3; June/Dec.
Measured Water Levels
Simulated Water Levels
50
0
-50
-100
-100
-50
0
50
ooooo 07S1E06M01
□□□□□ 07S1E07F01
The Best Fit Line Is:
y 0.473x − 21.77
95 Percent Predictior
Intervals